

MassDOT Snow and Ice Control Program

2017 Environmental Status and
Planning Report

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Final



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List of Acronyms

ABP	Accelerated Bridge Program
ACEC	Areas of Critical Environmental Concern
BMPs	Best Management Practices
BOD	Biological Oxygen Demand
CaCl ₂	Calcium Chloride
Ca(OH) ₂	Calcium Hydroxide
CDS	Crash Data System
CMA	Calcium Magnesium Acetate
CP	Cathodic Protection
CSMR	Chloride-to-Sulfate Mass Ratio
DCR	Department of Conservation and Recreation
DIC	Dissolved Inorganic Carbon
DWP	Draft Work Plan
DWWD	Dedham-Westwood Water District
ECE	Electrochemical Chloride Extraction
EEA	Energy and Environmental Affairs
ESPR	Environmental Status and Planning Report
FHWA	Federal Highway Administration
GEIR	Generic Environmental Impact Reports
GPS/AVL	Global Positioning System/Automatic Vehicle Locator
HOC	Highway Operations Center
KAc	Potassium Acetate
LCC	Liquid Calcium Chloride
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MassPort	Massachusetts Port Authority
MBTA	Massachusetts Bay Transportation Authority
MDSS	Material Decision Support System
MEMA	Massachusetts Emergency Management Agency
MEPA	Massachusetts Environmental Policy Act
MESA	Massachusetts Endangered Species Act
MgCl ₂	Magnesium Chloride
MHD	Massachusetts Highway Department
MinnDOT	Minnesota Department of Transportation
MNHESP	Massachusetts Natural Heritage and Endangered Species Program
MOA	Memorandum of Agreement
MTA	Massachusetts Turnpike Authority
NaCl	Sodium Chloride

NaAc	Sodium Acetate
NBI	National Bridge Inventory
NHDES	New Hampshire Department of Environmental Services
NHDOT	New Hampshire Department of Transportation
NHESP	Natural Heritage and Endangered Species Program
OGFC	Open Graded Friction Course
PACE	Performance and Career Enhancement
PCC	Portland Cement Concrete
PDO	Property-Damage Only
PWS	Public Water Supplies
RMV	Registry of Motor Vehicles
RO	Reverse Osmosis
RSZs	Reduced Salt Zones
RWIS	Road Weather Information Systems
SICP	Snow and Ice Control Program
SIMS	Snow and Ice Management System
SMCL	Secondary Maximum Contaminant Level
SOP	Standard Operating Procedures
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
UMASS	University of Massachusetts
VAOT	Vermont Agency of Transportation
VMT	Vehicle Miles Traveled
WPI	Worcester Polytechnic Institute
WSI	Winter Severity Index

Introduction/ Executive Summary

Introduction

The Massachusetts Department of Transportation (MassDOT) has prepared this Environmental Status and Planning Report (ESPR) to provide a status update on the potential environmental impacts associated with its statewide Snow and Ice Control Program (SICP) in accordance with the Certificate issued by the Secretary of the Executive Office of Energy and Environmental Affairs (EEA) on May 27, 2016. A similar ESPR was completed in 2012 and similar Generic Environmental Impact Reports (GEIRs) were completed in 1978, 1995 and 2006. MassDOT changed to an ESPR format on a 5-year cycle after Special Review Procedures were established in the 2006 Certificate consistent with Massachusetts Environmental Policy Act (MEPA) regulations 301 CMR 11.09.

Prior to preparing this ESPR, MassDOT submitted an ESPR Work Plan to the EEA Office which was noticed in the Environmental Monitor on April 20, 2016 for agency and public review. The review comments and information requests received during this review were incorporated into the May 2016 MEPA Certificate. This document focuses solely on the MassDOT SICP and does not evaluate SICP Operations performed by other state agencies, municipalities, or on commercial properties located throughout the Commonwealth.

This ESPR provides an update on the tools and technologies used by MassDOT to enhance winter maintenance operations and reduce the use of road salt and sand as well as program costs and environmental impacts.

The following provides a brief description of each chapter:

- **Chapter 1** – Describes the SICP overall management and operational aspects including policies and procedures, the roadway network maintained, annual training, annual deicing material usage and related annual program costs. Use of a Winter Severity Index (WSI), to assess the effectiveness of various efficiency measures and equipment upgrades, is also explained.
- **Chapter 2** – Describes the Salt Remediation Program and Reduced Salt Zone (RSZ) Program used to minimize the effects of deicing material usage around public water supply wells as well as a summary of relevant research pertaining to the environmental impacts associated with deicing usage.
- **Chapter 3** – Describes the latest tools and technologies used to be more efficient and increase the effectiveness of deicing chemicals including use of liquid deicers for pre-wetting and pretreatment, closed-loop controllers, road weather information systems (RWIS') and pavement friction sensors.
- **Chapter 4** – Presents an update on the potential corrosion effects to roadway infrastructure and the recent methods used to minimize corrosion damage.
- **Chapter 5** – Presents relevant research findings on how poor road conditions and reduced mobility during winter weather may adversely affect local and regional economic activity. The potential economic impact that SICP activities may have on environmental resources is also discussed.
- **Chapter 6** – Describes minor changes to the Special Review Procedures for future ESPRs.
- **Chapter 7** – Provides a list of planned future initiatives to further enhance the SICP efficiencies and address ongoing or more recent environmental concerns.

Major Changes Since Completion of the 2012 ESPR

The following are some of the major changes to the SICP that have happened since the 2012 ESPR:

- In 2012, Sam Salfity became the new Director of SICP Operations. Mr. Salfity is responsible for budget planning, district coordination, implementing new policies and equipment upgrades within the SICP.
- The RWIS network has been expanded with new capabilities/sensors added including passive friction sensors and video cameras to monitor pavement conditions, which provides continuous data to district personnel on pavement conditions and deicing material needs.
- MassDOT has continued to upgrade its equipment fleet and facilities with new tanker trucks, tow plows, pavement sensors, storage facilities, and the use of variable message signs on major roadways.
- MassDOT has constructed new salt storage facilities in Andover (2), Billerica (1), Braintree (1), Chelmsford (1), and Rowley (1) that allow indoor loading and unloading.
- Contractor service agreements have been revised to require contractors to use closed-loop, ground-speed controllers as well as pre-wetting equipment and be compensated for training participation.

Executive Summary

Operations

The road network that MassDOT maintains for snow and ice control purposes has remained much the same over the last seven (7) years at just under 16,000 lane-miles across six different maintenance districts. This represents approximately 20% of the total estimated roadway lane-miles in the Commonwealth. The last major change was in 2010, following the merger with the Mass Turnpike Authority, which increased the overall lane mileage by 15%. MassDOT also assumed maintenance of the Tobin Bridge and approximately 729 lane-miles of Department of Conservation and Recreation (DCR)-owned roads.

MassDOT continues to incorporate new tools and technologies into its SICP including more widespread use of liquid deicers for pretreatment and pre-wetting, new pavement sensors, flexible plow blades, tow plows, AVL/GPS technology and front-end loader scales, to name a few. MassDOT has revised its contractor reimbursement rates to compensate them for equipment upgrades and use of closed-loop controllers to be more efficient with deicing chemicals. All contractors must now have closed-loop controllers in their spreader trucks as well as pre-wetting equipment with a flow meter. Previously, use of closed-loop controllers was financially incentivized but not mandatory. Hired equipment must also be calibrated by an approved, third-party calibrator and be inspected by MassDOT personnel prior to, and throughout the winter season.

MassDOT has been using a Winter Severity Index (WSI) to assess how annual road salt usage compares with changes in winter severity conditions. The WSI, originally developed by the State of Washington in the early 1990s as part of a Strategic Highway Research Project, provides a relative index of the severity of winter weather during a winter season and is based on daily snowfall, daily minimum and maximum temperatures, and the number of days with frost potential. The WSI value is calculated on a monthly basis and then averaged over a 5-month period (November-March) to provide a seasonal average. Comparing annual salt usage to the WSI value helps to explain how winter weather influences the amount of salt used from year to year. It can also be used to assess how equipment upgrades or other technology advances affect annual salt usage relative to that used prior to the newer equipment or practices under similar winter weather severity conditions.

In the last seven (7) years, following the adoption of various anti-icing practices and other efficiency measures, MassDOT has reduced its average annual statewide road salt usage by approximately 24% on a ton per lane-mile basis compared to the average annual usage between 2001 and 2010 while adjusting for differences in winter weather severity. In 2014/15, which was the most severe winter in the past 17 years, MassDOT used approximately 30% or roughly 125,000 tons less road salt than that used in the winters of 2003 and 2005, which had slightly less severe winter weather.

MassDOT spends on average approximately \$1.5 million per year on its Salt Remediation Program to investigate and remediate complaints. The annual costs vary depending on the number and type of cases and the geographic extent of the affected areas. Most of the complaint cases and remediation activity have been related to private wells associated with individual residences. Since 2000, just over 200 remediation claims have been submitted representing an average of approximately twelve (12) cases per year. In the last five (5) years, fifty-six (56) claims were received compared to sixty-eight (68) claims in the previous five years, indicating a possible declining trend. Most recently, nine (9) claims were received in 2015 and seven (7) claims were received in 2016. All but fifteen (15) of the claims received since 2000 have been remediated and closed, and those that remain open and are still being investigated for remediation.

MassDOT maintains sixty-two (62) Reduced Salt Zones (RSZs) throughout the state consisting of approximately 624 miles and 1,752 lane-miles of roadway. These RSZs were established decades ago to minimize sodium inputs around certain public well and private well locations. No new RSZs have been added in the last 10 years. To reduce the amount of sodium used in RSZs, MassDOT applies a 50:50 mix of sand with salt and, to lesser extent, Pre-mix with salt in each application. However, over the years, District personnel have found that using half the amount of deicing material in each application (i.e. 120 lbs/ln-mi) compared to 240 lbs/ln-mi in a typical application made it much more difficult to prevent snow and ice from freezing to the pavement and diminished their ability to maintain reasonably safe road conditions. This was particularly true during cold periods, when snow and ice would often freeze to the pavement relatively soon after applications. Quite often, depending on temperatures, additional and/or more frequent applications were needed in RSZs to minimize snow pack buildup. Sand provides no deicing benefits and only a brief traction benefit before the sand becomes pulverized by vehicle traffic. In the end, the need for more applications typically results in as much salt being used in RSZ areas as that being used on regularly treated roadways, especially during colder winters.

At the same time, MassDOT incurs increased personnel and equipment costs to perform frequent road surface monitoring and additional applications. MassDOT estimates that maintaining RSZs adds an additional \$2,000 per lane-mile or \$3.5 million per year compared to the costs for a conventionally-treated roadway. The added costs are also due to the post-season cleanup of sand from the road drainage system. Sand poses other environmental threats with respect to siltation of stream habitats, increased turbidity and phosphorus loading.

MassDOT has been more successful in reducing overall salt usage through recent equipment upgrades, anti-icing techniques and enhanced training as compared to using sand in a 50:50 application mix in RSZ areas. As noted above, the limited effectiveness of the sand:salt mix in RSZ areas ends up requiring more applications to prevent snowpack/ice formation especially at colder temperatures. As a result, MassDOT plans to gradually phase out the use of sand in RSZ areas and focus its efforts on broadening and refining the available tools and technologies statewide to continue to increase the efficiency and effectiveness of road salt. This will not only result in lower salt usage but more consistent operations, better road surface conditions and potential cost savings in less time needed to monitor road conditions between applications, less handling of other materials (i.e. sand/Premix) and less time to conduct post-winter cleanup of sand in RSZ areas. This would also reduce environmental impacts associated with the use of sand, particularly with respect phosphorus loading.

Environment

MassDEP's database of reported sodium data in Public Water Supplies (PWS) (as of August 2016), contains 16,345 records of sodium sampling results and 3,594 chloride sampling results going back to 1993. A total of 1,821 different PWS were identified as having reported sodium data. Of the PWS with sodium data, a majority (56%) or 1,030 consist of non-community PWS serving a transient population while another 487 consist of community PWS, and 304 consist of non-transient, non-community PWS. Nearly half or 946 PWS that have reported sodium data were identified as having at least one source within a 0.5-mile of a MassDOT roadway.

The average and maximum sodium concentrations for PWS located within and outside a 0.5-mile radius of a MassDOT roadway were compared based on reported data collected in the last 5 years between 2012 and 2016. This more recent data was used to focus on current conditions and minimize any bias from older and less relevant data that may be associated with inactive sources. The results indicate that approximately 52% of all PWS with reported sodium data located within a 0.5-mile of a MassDOT roadway had an average sodium concentration above 20 mg/L compared to 38% of the PWS located more than a 0.5-mile from a MassDOT road. Approximately 18% of the PWS located within a 0.5-mile of a MassDOT road had an average sodium concentration above 60 mg/L as compared to 8% of the PWS located more than a 0.5-mile from a MassDOT roadway. Approximately 9% and 3% of the PWS located inside and outside of a 0.5-mile radius of a MassDOT roadway, respectively, had an average sodium concentration above 100 mg/L.

In review of maximum sodium concentrations, approximately 55% of the PWS located within a 0.5-mile of a MassDOT road had a maximum sodium concentration above 20 mg/L compared to 43% of the PWS located beyond a 0.5-mile from a MassDOT road. The percentage of PWS located within and beyond a 0.5 mile of a MassDOT roadway that had a maximum reported sodium concentration above 60 mg/L was 25% and 15%, respectively. Similarly, 18 and 8 percent of the PWS located within and beyond a 0.5-mile radius of a MassDOT roadway, respectively, had a reported maximum sodium concentration above 100 mg/L.

Although the results indicate that there are more PWS closer to a MassDOT road that had higher average or maximum sodium concentrations compared to PWS located more than a 0.5 mile away, this does not necessarily verify that the higher occurrence is directly related to MassDOT SICP operations since there are many contributing factors that influence sodium levels in PWS. PWS within a 0.5-mile of a MassDOT road are more likely to be located in urbanized areas where there are greater densities of roadways and PWS, whereas, PWS identified as being more than a 0.5-mile from a MassDOT road are more likely to be in rural, less developed areas of the state. Urbanized areas also have greater amounts of impervious surfaces associated with commercial parking lots compared to rural areas. Road salt usage on municipal roads and parking lots are likely to contribute to the greater propensity for higher sodium levels in PWS within an urbanized area and a 0.5-mile of MassDOT road. Other factors including surrounding land uses, proximity to brackish or ocean waters, groundwater flow direction, underlying surficial deposits, and whether the PWS uses treatment chemicals to adjust for pH and hardness can influence sodium levels but were not evaluated in this analysis.

In review of municipal PWS, particularly those in more urbanized areas, several have shown recent increases when comparing average sodium concentrations from 2013 to 2016 to those reported in 2008 to 2012. These include municipal water supplies in the towns of Auburn, Billerica, Cambridge, East Chelmsford, Marlborough, Millbury, North Chelmsford, Weymouth and Wilmington. These increases occurred despite MassDOT having reduced its salt usage in recent years, which suggests that either other sources are contributing to the sodium increases or there is a significant lag in travel time such that the effects of the salt use reductions are not being detected yet. Given the amount of commercial development that has occurred in the last decade or two, the amount of road salt used on commercial parking lots is likely to have an increasing influence on sodium levels

in surface water and groundwater in the more urbanized areas of the state. Detailed hydrologic investigations and loading assessments would be needed to definitively determine relative influence of the various sources and the site-specific factors are having on sodium levels.

According to the MassDEP database, chloride levels were reported in 475 PWS, which includes over 1,100 individual water sources. Of these, 26% had an average chloride concentration above 100 mg/L and 18% had average chloride concentrations between 100 and 250 mg/L. Approximately 8% of the PWS consisting of thirty (30) PWS have an average chloride concentration above 250 mg/L.

The 2014 Massachusetts Integrated List of Waters lists six (6) water bodies as being chloride-impaired. Four (4) of these streams are located along the I-93 corridor in the towns of Andover, Wilmington, and Tewksbury and include an unnamed tributary to Martin's Brook in Wilmington, an unnamed tributary to the Shawsheen River near Dascomb Road in Tewksbury and Pinnacle Brook and Fish Brook in Andover. Although these streams are located near a major MassDOT roadway, the designated impaired segment in most streams begins upstream of the roadway, which indicates that chloride levels are already elevated prior to entering the roadway corridor perhaps due to other sources contributions in the watershed.

MassDOT has initiated several measures to minimize of road salt usage in environmentally sensitive areas and especially adjacent to Kampoosa Bog. MassDOT initiated a pilot study to develop a wireless system to upload road salt usage data electronically recorded by closed-loop controllers along the roadway sections adjacent to Kampoosa Bog. Although it took a few seasons to work out the electronic hardware and software glitches, district personnel are now able to track road salt usage along these sections of road. District personnel plan to build on this early success and improve the tracking and reporting system. MassDOT is currently funding a study to be done by Natural Heritage and Endangered Species personnel to map the extent of the sedge fen habitat area as well as the distribution and limits of cattail plants and other invasive species.

Infrastructure Corrosion

It is difficult to determine how much of the corrosion on our nation's roadway infrastructure is due to deicing chemical usage or other unrelated factors. The National Bridge Inventory (NBI) Database (last updated in March 2016) indicates that approximately 53% of the estimated 612,000 roadway bridges in the U.S. are more than 50 years old), which is longer than the average design life for most bridges. Approximately 23% are more than 60 years old. Of the approximately 9.6% or 58,800 bridges that are rated as structurally deficient, nearly three-quarters or 73% of these structurally deficient bridges are more than 50 years old.

In 2008, MassDOT launched an Accelerated Bridge Program (ABP) to quicken the process of repairing and reconstructing structurally-deficient bridges located throughout the state. At the time, slightly more than 10% of the over 5,000 bridges located in the State of Massachusetts were considered structurally-deficient. As of October 1, 2016, the number of structurally-deficient bridges in the state has dropped to 432, representing a 20% drop in the number of structurally-deficient bridges. The percentage of structurally-deficient bridges is now down to closer to 8.0% of the total number of bridges in the state. More than 90% of the structurally-deficient bridges are over 50 years old based on 2015 NBI data.

MassDOT has updated their bridge design manual and standards to include various corrosion protection measures including use of epoxy-coated steel, membranes, sealants, weathered steel and applying metal coatings through galvanizing and/or metalizing the steel components. Metalizing and galvanizing provides more effective, long-term protection for steel than regular coatings.

Economic Impact

Massachusetts vehicle crash data collected from 2006 to 2014 (latest available) indicates that the average winter daily crash rate declined by approximately 9% (or approximately 36 fewer vehicle crashes per day) between 2011 and 2014 compared to the previous five years (2006 to 2011). There were approximately 5,400 fewer winter-weather related crashes, on average, each season over the last 4 years, despite 3 out of the 4 recent winters being relatively severe winters. The lower daily crash rate in recent years suggests that the anti-icing practices as well as equipment upgrades may be providing better road conditions during winter months, particularly since traffic volumes have remained the same, if not increased since 2011. Other factors such as improved driving behavior may have also contributed to the decline in winter crash rates.

Fewer vehicle crashes during the winter not only represents a significant public safety benefit but an economic benefit as well. Based on an estimated average cost per crash of \$33,325, using national statistics for all motor vehicle crashes, the effect of 5,400 fewer winter related crashes could result in a cost savings of approximately \$180 million per year. Again, given that winter-related crashes tend to be less severe and involve more property damage only (PDO) crashes compared to non-winter crashes, the average cost per crash is likely to be lower than that for non-winter crashes. On the other hand, since many winter weather PDO crashes tend to go unreported, the reduction in winter-related crashes could be even higher resulting in an even greater benefit.

The Commonwealth's transportation system plays a vital role in supporting economic activity and related travel as part of the state's economy. In 2014, domestic and international travelers in Massachusetts spent nearly \$19.5 billion on transportation, lodging, food, entertainment, recreation and incidentals. Domestic travelers accounted for approximately 86% or \$16.8 billion of these expenditures. Approximately 68% of the visitors drove their own vehicles into the state. Domestic travel spending in 2014 generated approximately \$1.1 billion in tax revenues for the both the state and local governments. Each domestic and international travel dollar produced 3.8 cents and 2.4 cents on state and local tax receipts, respectively. Travel spending for 2014 also produced approximately 212,200 jobs and \$7.9 billion in payroll income for Massachusetts residents.

A study conducted by IHS Global Insight (2010) estimated that a one-day shutdown in Massachusetts could result in an economic impact of \$265.1 million. Much of the impact was attributed to lost wages for hourly workers (\$194 million), but also included estimated losses in retail sales (\$40.5 million), and lost federal, state, and local tax revenue (\$30.5 million). These cost estimates assume that all businesses and government agencies would be closed due to impassable roads and the closure of other modes of transit. Even if the IHS estimated economic impact was reduced by 25% or 50% to reflect that some employees are still able to work or work from home and some level of retail activity is still likely to occur, the adjusted cost estimates of approximately \$130 to \$200 million still represent a relatively large economic impact for a one-day snow event.

A previous study estimated that typical road salt applications could result in annual economic impacts of approximately \$2,320 per lane mile due to lost or degraded ecosystem services provided by roadside forested and wetland areas (Kelting and Larson, 2010). The estimates were based on model simulations of varying levels of impact resulting from diminished vegetation growth, reduced nutrient uptake, increased sediment erosion at varying distances from the roadway. This estimated impact assumed a 1% decline in services provided by lakes and rivers and a 5% decline in ecosystem services provided by forested areas. The authors note the estimates have a wide margin of error and are highly dependent on site-specific factors including the type, extent and health of the roadside vegetation, underlying soils, the connection to water-dependent services and the influence of surrounding land uses along roadside areas. Applying the estimated lost ecosystem services value of \$2,320 per lane-mile to the approximately 15,900 lane-miles maintained by MassDOT results in an estimated economic impact of approximately \$37 million per year due to MassDOT road salt usage.

Operations and Deicing Chemical Usage

1.1 Overview of MassDOT Snow and Ice Control Program (SICP) Operations

The Massachusetts Department of Transportation (MassDOT) was formed by the Transportation Reform Act, enacted in November 2009, which integrated four separate transportation agencies into one agency. MassDOT has four divisions including the Highway Division, the Registry of Motor Vehicles (RMV) Division, the Rail and Transit Division (includes the Massachusetts Bay Transportation Authority, or MBTA), and the Aeronautics Division (previously part of the Massachusetts Port Authority, or MassPort).

The Highway Division is comprised of the former Massachusetts Highway Department (MHD), which merged with the Massachusetts Turnpike Authority (MTA) and is responsible for maintaining all interstate, arterial roadways and bridges previously maintained by the former MHD as well as several urban parkways previously maintained by the Department of Conservation and Recreation (DCR). The Highway Division is divided into six regional Districts, which operate under the direction of the Boston Headquarters office. Winter maintenance involving plowing and removal of snow, deicing material applications, and monitoring of weather and road conditions, is a shared responsibility coordinated between the Director of SICP Operations, District SICP Engineers, and the Highway Operations Center (HOC). These operations are described further below.

1.1.1 Program Organization and Management

The SICP refers to all operations conducted by the Highway Division to maintain reasonably safe road conditions on highways, bridges, and parking facilities during winter weather. The overall goal of SICP is to maintain roadway conditions that allow motorists to maintain vehicle control and mobility at reduced vehicle speeds during winter weather. The primary means to achieving this goal consist of: (1) plowing or physical removal of snow from the roadway; and (2) timely application of deicing materials.

MassDOT's organizational structure assigns key personnel with defined roles and responsibilities to initiate, manage, and track various operations (see Table 1.1 below). Most of MassDOT's management and operations personnel have years, if not decades, of experience, which is highly valuable in terms of understanding how various weather-related and site-specific factors affect road conditions. In addition, MassDOT relies on a weather forecasting contractor to provide detailed, area-specific weather forecast updates as well as utilizes road and weather information gathered at the District level to decide when to initiate SICP operations.

Approximately forty (40) RWIS stations are located throughout the state, which provide weather and pavement condition data (discussed more in Chapter 3). During major statewide snow events, as many as 4,000 pieces of equipment (e.g., plows, loaders, tanker trucks) may be placed into service to provide sufficient geographic coverage. Approximately 90% of the equipment needs are provided by hired (private) contractors.

1.1.2 MassDOT SICP Roles and Responsibilities

Table 1.1 lists the principal roles and responsibilities for the various SICP personnel and management levels. This list of responsibilities, however, by no means covers all aspects of the activities performed under the SICP.

Table 1.1: Primary MassDOT SICP Personnel Roles and Responsibilities

MassDOT Role	Snow and Ice Program Responsibilities
Lead Snow and Ice Engineer	Develop and update SICP Operations policies and procedures
	Coordinate with District Engineers on spreader routes and equipment needs
	Review/Approve equipment purchase requests
	Coordinate/approve contractor agreements for hired equipment
	Monitor weather forecasts and coordinate statewide readiness/response to storm events
District Maintenance/Operations Engineer	Review and Approve spreader and plow routes on an annual basis
	Coordinate with SICP Engineer on reviewing contractor equipment needs
	Review and approve state personnel assignments
	Review and approve materials and contractor equipment expenditures
	Coordinate emergency operations for roadway incidents
	Assess salt storage infrastructure conditions and general housekeeping measures
District Snow and Ice Engineer	Coordinate the district personnel training with the Lead Snow and Ice Engineer
	Review and recommend updates to spreader and plow routes prior to each season
	Coordinate with Area Supervisors on deicing material requests and schedule material deliveries
	Recommend contractor selection based on equipment type and quantity needs
	Determine equipment mobilization start and end times based on weather and RWIS data
	Review & track deicing material usage/ inventory via Snow & Ice Management System (SIMS) reports
	Coordinate with after-hour road patrols and operations with the HOC and Area Supervisors
Area Supervisor	Coordinate with Depot Foremen each Depot (approx. 7 to 11 depots in each District Area)
	Patrol maintenance area and report on road/weather conditions to District SICP Engineer
	Respond to emergency operations and roadway incidents
	Assist in determining start and end times for hired equipment on specific routes
Depot Foreman	Coordinate pre-season activities including assigning plow and spreader routes, processing contractor equipment agreements, and coordinating repairs on state-owned equipment
	Perform call-outs for state personnel and contractors at the beginning of an event
	Assign /adjust plow routes for each event based on operational needs
	Coordinate with Route Coordinators regarding road conditions and material needs
	Conduct periodic checks of spreader equipment calibration throughout the season
Plow Supervisor/ Route Coordinator	Patrol roadways and communicate road and weather conditions to the Depot Foreman
	Inform Depot Foreman when plows are no longer needed based on road & weather info
	Organize / synchronize plows and spreaders to ensure effective operations

Note: This is not intended to represent an all-inclusive list of the various roles and responsibilities performed by MassDOT SICP personnel

1.1.3 MassDOT's SICP Roadway Service Area

MassDOT maintains approximately 16,000 lane-miles of roadway across six different maintenance districts for snow and ice control purposes. Table 1.2 provides a summary of the total lane mileage and Interstate lane miles maintained by each District based on the 2010 Statewide Road Inventory. Following the merger with the MTA in 2010, the total lane mileage maintained increased by 15%. MassDOT also assumed maintenance of the Tobin Bridge and associated approach/connector roads, previously maintained by MassPort, and maintains approximately 730 lane-miles of DCR-owned roads. Figure 1.1 shows the geographic limits of the six (6) maintenance districts as well as a summary of the total lane-miles maintained in each district.

All totaled, MassDOT maintains approximately 20% of the 78,000 +/- lane-miles of roadway located within the Commonwealth according to the 2010 MassDOT Road Inventory. The other 80% of the roadway lane miles identified in this state are maintained by various municipalities, private land owners or other state agencies.

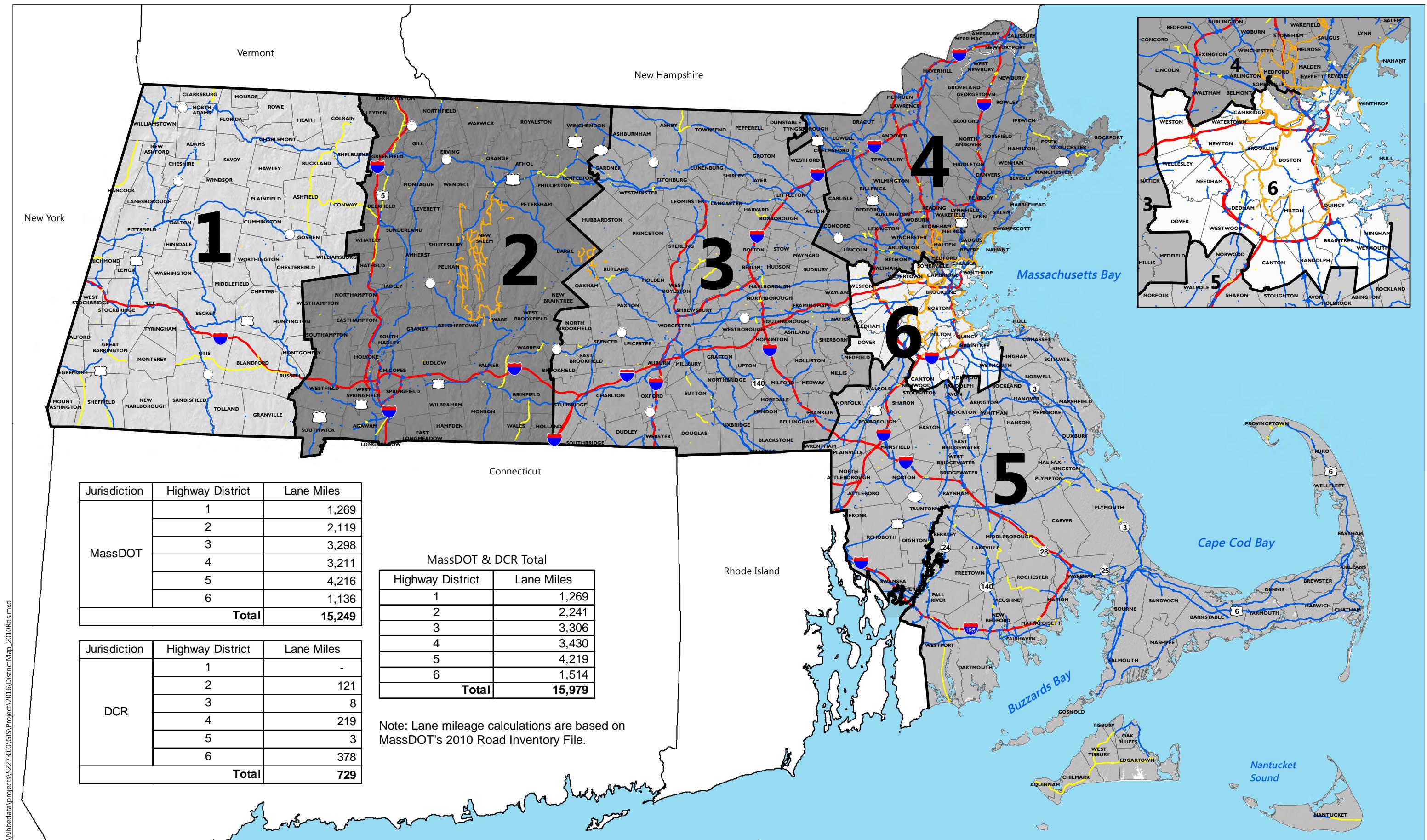
Table 1.2: Total and Interstate Roadway Lane-Miles¹ Maintained in Each District

DOT District	Total Roadway Lane Miles ¹	Interstate Roadway Lane Miles	Percent of Interstate Roadway Lane-Miles
1	1,269	251	20%
2	2,241	763	34%
3	3,306	1,378	42%
4	3,430	1,168	34%
5	4,219	936	22%
6	1,514	522	34%
Total:	15,979	5,018	31%

Notes: ¹Lane miles estimates are based on 2010 Road Inventory and are subject to change as a new 2017 Snow Plow Route GIS Layer was recently completed but is undergoing verification review. Lane-miles are determined based on the pavement width divided by 11-foot travel lanes multiplied by the linear length of road for all roadways identified as being under MassDOT jurisdiction.

Approximately 31% of MassDOT's road network is comprised of multi-lane interstate roads and even more so in District 3. Interstate roads especially in urban areas generally require more intense operational activity and greater equipment demands to maintain reasonably safe road conditions and vehicle mobility for traffic volumes that exceed over 200,000 vehicles per day. In these urban areas, SICP operations are typically needed 24 hours a day, 7 days a week whereas, in more rural areas and even on secondary roads, with lower and less consistent traffic volumes, SICP operations can be done less frequently and at a lower level of service, particularly during overnight hours. Scheduling plowing operations and material applications can be also quite challenging when peak traffic volumes reach 10,000 to 20,000 vehicles per hour during peak commuting hours.

The amount of Interstate roadway miles, roadway density, geographic extent of urban areas and high traffic volumes are just some of the key aspects that make MassDOT's road network different than other New England states and impose greater demands on equipment, labor and material usage relative to other state transportation agencies. Not only does MassDOT maintain the highest number of lane-miles (15,900 lane-mi), which is 50% more than the second highest amount (Connecticut: 10,800 lane-mi) and about twice that in Rhode Island, Vermont, New Hampshire and Maine (3,300 to 8,500 lane-mi), but also has some of the highest and most persistent traffic volumes relative to other states. The estimated annual vehicle miles traveled and number of registered vehicles in Massachusetts are approximately 2 to 3 times higher than that in any other New England state reflecting the greater usage and travel demands on the state roadway system (Mahoney et al, 2015). Each day, up to 5 million vehicles from within and surrounding states collectively travel over 154 million miles on roads throughout Massachusetts (MassDOT Transportation Planning Fact Sheet, 2016).



Legend

- Interstate
- Collector
- Arterial
- DCR Roads



0 7.5 15 30 Miles

2017 Snow & Ice Control ESPR

MassDOT

June 14, 2017

Figure 1-1
MassDOT District and Road Inventory
Summary Map

massDOT
Massachusetts Department of Transportation

Source: MassGIS, MassDOT, VHB

1.1.4 Coordination with Other State Agencies

Through a Memorandum of Agreement (MOA), which is currently being updated in 2017, MassDOT and DCR have outlined specific locations of snow and ice removal responsibilities along DCR roads. As such, MassDOT has assumed curb-to-curb snow and ice removal responsibility for approximately 380 lane-miles (60%) of DCR's Urban Parkways in the Boston area, including, most recently, portions of Morrissey Boulevard in Dorchester to South Portland. DCR, however, still retains responsibility for maintaining sidewalks and pedestrian routes along these urban roadways. MassDOT is also updating its Statewide Pedestrian Transportation Plan which will provide updated guidance for communities to improve pedestrian access and walkability within their jurisdictions. The Plan, expected to be completed in early 2018, will also provide guidance on prioritizing snow removal operations along pedestrian routes during winter months, which is primarily performed by municipal personnel and/or property owners.

For other DCR roadways and pedestrian routes (sidewalks, pathways, and footbridges), DCR has its own protocols for snow and ice removal, as outlined in DCR's *Standard Operating Guide for Winter Weather Events* (DCR, 2015). DCR has its own snow removal equipment and material storage facilities as well as a Statewide Storm Center, which coordinates and monitors its SICP removal operations during winter storm events. DCR operations are monitored by the MassParks Storm Center, as outlined in DCR's Standard Operating Guide for Winter Weather Events. MassDOT and DCR share salt storage facilities in Nahant, Milton, and Stoneham.

MBTA is responsible for maintaining commuter rail, subway, bus, and boat transportation services throughout the Commonwealth. MBTA operates their own SICP independent of the MassDOT roadway program. MBTA recently updated its snow and ice removal protocols in its *2015-2016 Snow & Ice Operations Plan* (MBTA, 2015). This plan describes roles, responsibilities, operations and management of personnel, equipment, and material used to keep transportation services running smoothly and safely during winter storm events.

MassDOT personnel are also in communication with the Highway Operations Center (HOC) during winter weather conditions, which is staffed 24 hours a day, 7 days a week to monitor traffic flow and assist emergency response and highway maintenance personnel. This role intensifies during winter events when travel conditions tend to deteriorate. The HOC continually monitors traffic and roadway conditions via numerous surveillance roadway cameras and RWIS stations. As traffic incidents occur and/or poor roadway conditions are detected, these are reported to the HOC, and the information is relayed to the District radio rooms (aka District Storm Desks) to assist in coordinating operations and address roadway conditions.

1.2 S&I Control Program Costs

As shown in Table 1.3, the average annual program cost for the last five years was approximately \$100 million but can fluctuate by as much as 50% or more depending on the severity of winter weather. Weather-related factors such as the severity, duration, and number of winter storms, as well as temperature variability, can have a major impact on SICP Operations. During the unusually mild winter of FY12, the annual program costs were approximately \$41.5 million, whereas in FY15, an unusually severe winter, the SICP costs were approximately \$161 million. The FY15 winter had more than 100 inches (i.e., ~9 feet) of snow over much of the state and was also one of the coldest winters in recent history.

The deicing material costs generally accounts for approximately 25 to 35% of the annual SICP budget. Hired equipment typically accounts for another 55 to 65% of the annual budget. MassDOT personnel costs generally account for approximately 5 to 15% of the annual budget. Capital costs associated with equipment purchases and facility improvements are not included in the annual operating budget. Maintenance costs associated with post-winter sand cleanup, bridge washing or other infrastructure maintenance are not included in the SICP operating budget. Similarly, monitoring, assessment and remedial activities associated with drinking water or other resource are not included in the SICP budget as these activities are performed by Environmental Services.

Table 1.3: Summary of Annual SICP Operating Costs Over Last 5 Years

FY	Materials	Hired Equipment	State Personnel	Total Cost
12	\$11,832,625	\$20,190,505	\$9,512,711	\$41,535,841
13	\$24,340,182	\$59,531,998	\$12,225,462	\$96,097,642
14	\$42,784,527	\$74,407,464	\$13,378,108	\$130,570,099
15	\$45,739,191	\$98,831,487	\$16,538,198	\$161,108,876
16	\$27,231,953	\$48,577,517	\$7,801,082	\$83,610,553
Average:	\$30,385,696	\$60,307,794	\$11,891,112	\$102,584,602

1.2.1 Cost of Maintaining Reduced Salt Zones and other Mitigation Practices

As discussed more in Chapter 2, maintaining Reduced Salt Zones costs approximately \$2,000 more per lane-mile on an annual basis compared to a typical roadway. The increased costs relate in part to the use of supplemental materials such as Pre-mix and the additional personnel time needed to monitor road conditions, and perform additional plowing and/or applications to maintain safe roadway conditions that are reasonably consistent with adjacent non-RSZ road segments. More frequent pavement monitoring is required because only half as much deicing material is applied in each application using the 1:1 mix of salt or Pre-mix and sand. District personnel strive to maintain consistent, ice-free road conditions and avoid variable surface conditions that can lead to unsafe roads. This can be especially challenging at colder temperatures. With an added average annual cost of \$2,000 per lane mile, which varies depending on winter severity, requires an additional \$3.5 million per year to maintain approximately 1,753 lane-miles of road designated as RSZ's within the state.

1.2.2 Contractor Reimbursement Rate Incentives

MassDOT has revised the contractor agreements and reimbursement rates to compensate them for acquiring pre-wetting equipment and closed-loop controllers in order to be much more efficient with deicing chemicals. All contractors must have closed-loop ground speed controllers in their spreader trucks as well as pre-wetting equipment with a flow meter. Hired equipment must also be calibrated by an approved, third-party calibrator and be inspected by MassDOT personnel prior to, and throughout, the winter season. All closed-loop systems must be able to report material use data including: pounds or tons of material applied, types of material, gallons of liquid dispensed, miles traveled, location of dispensed material, lane-miles applied, time of application, and application rates. The revised compensation rate also accounts for the extra time involved with data reporting with closed-loop controllers (MassDOT, 2014).

As an added incentive to get inspections done early, contractors that meet the early readiness requirements identified in the current SICP Agreement are given an Early Sign-up Bonus. In addition, contractors that are called-in and report to work prior to December 1st and after March 31st are granted an Extended Season

Bonus. These incentives are meant to encourage contractor readiness and good management practices during snow and ice removal activities as well as to increase roadway safety during the winter season.

The current SICP Agreement compensates contractors to attend 'tailgate" training sessions, which helps MassDOT personnel and contractors exchange ideas and gain a better understanding of the overall program goals which include environmental stewardship, highway and personnel safety, and operational efficiency.

1.3 Average Annual Road Salt Usage

Table 1.4 presents the average annual salt usage in tons per year for each district in the last seven (7) years compared to the average annual usage in the previous ten (10) years (FY01-FY10). On a statewide basis, the average annual salt usage has been approximately 40,000 tons less in the last 7 years compared to that used in the previous 10 years. In comparing recent usage to historical usage on a district by district basis, Districts 1 and 5 used slightly more, District 2 used about the same, District 3 used slightly less and District 4 used much less. However, it is important to note that the lane-mileage maintained by each district changed considerably after the merger with the Mass Turnpike Authority and the addition of several DCR roads starting in FY2011. The lane-miles in Districts 1, 2 and 5 increased by more than 20% while the lane-miles in District 4 decreased by approximately 20 percent. The merger also resulted in the creation of District 6. Thus, to conduct a more accurate or direct comparison of recent annual salt usage with historical usage, it is best done using tons per lane-mile while accounting for changes in winter weather severity conditions using a Winter Weather Severity Index (WSI). Section 1.6.5 describes how the WSI is derived, its year to year variability and how it is used to normalize the data for comparison between different years or periods. Salt usage is also presented in tons per lane-mile for each district and on a statewide basis.

Table 1.4: Recent Annual Salt Usage (tons/yr) (FY11 to FY17) Compared to Previous 10-Years (FY01-FY10)

District	FY01-FY10 Average	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY11-FY17 Average
1	39,874	52,983	25,833	37,331	52,613	54,811	21,700	54,142	42,760
2	59,531	62,188	21,767	54,190	65,000	85,000	42,000	76,983	58,161
3	139,945	129,114	50,131	126,554	143,304	134,337	99,156	143,289	117,984
4	160,999	119,023	36,841	78,082	86,840	87,371	54,850	79,216	77,460
5	110,120	130,748	67,117	110,043	134,104	152,000	88,904	104,100	112,431
6*	--	62,873	16,555	53,983	90,904	96,060	61,909	57,530	62,831
Total	510,468	556,839	218,244	460,183	572,765	609,579	368,519	515,260	471,627

Notes: *District 6 was established after the FY2010 winter season and therefore has no historical salt usage data. The total lane-mileage increased by approximately 15% starting in FY11 and was shifted amongst the various districts. Districts 1,2,3 & 5 gained lane-miles while District 4 lost lane-miles.

1.4 Other Snow and Ice Control Materials

In the last several years, the use of liquid deicers has increased considerably while the use of other granular materials such as Pre-mix and sand has decreased. Liquid deicers have increased the effectiveness of regular road salt and though anti-icing applications helps to prevent snow and ice from freezing or bonding to the pavement as its temperatures drop below freezing. Table 1.5 presents a summary of the statewide usage of

liquid deicers and other materials over the last five years. On a more localized basis, the type and quantity of material applied depends on pavement, topography, roadway, and weather conditions. Other factors involved in selecting appropriate deicer materials include pavement and air temperatures, temperature forecast, time of day, and material performance capabilities.

Table 1.5: Other Snow and Ice Control Materials Used by MassDOT Over the Last 5 Years

Fiscal Year	Liquid CaCl (gals) ¹	Liquid MgCl (gals)	Salt Brine (gals)	Pre-mix (tons) ²	Sand (tons)
13	28,592	1,209,810	68,700	2,413	17,106
14	6,292	1,401,941	137,376	2,720	26,676
15	0	1,532,412	161,500	2,316	35,074
16	0	1,068,711	154,279	6	15,134
17	0	1,596,890	171,796	601	15,573
Average:	7,102	1,361,953	138,730	1,656	21,912

Notes: ¹Liquid Calcium Chloride was previously used for prewetting but is no longer used. ²Not used in District 3 during FY11 and FY15. Not used in District 2 or 5 in FY16. Never used in District 6.

1.3.1 Sodium Chloride

Table 1.6 provides a description of the primary deicing chemicals used, their chemical composition, and the lowest temperature in which water will freeze (a.k.a. the "eutectic" temperature). MassDOT uses sodium chloride (NaCl) as granular road salt, as the predominant deicing chemical because of its relative low cost, effectiveness and availability in bulk quantities. Road salt generally costs between \$60 and \$80 per ton, depending on the supplier, volume purchased, and shipping cost. Sodium chloride is most effective when air and pavement temperatures are above 25°F, but is much less effective as temperatures drop to 20°F or lower.

Table 1.6: Physical Properties of Snow & Ice Control Materials

Material	Chemical Compound	Lowest Practical Melting Temperature	Typical Liquid Deicer Concentration
Sodium Chloride (Rock Salt, Road Salt or Liquid Brine) – Delivered mostly as granular rock salt; also made into a brine. Brine is used for pretreatment applications. Corrosive. Most cost-effective.	NaCl	20°F	23.3%
Calcium Chloride (Pre-mix)¹ Delivered as flakes or as liquid (LCC). Pre-Mix is used in RSZs to minimize sodium inputs. Can be corrosive. Higher cost. Limited use only. ²	CaCl ₂	-20°F	32%
Magnesium Chloride Delivered as a liquid. Used to either pre-treat roads or pre-wet road salt. Is effective at lower temperatures. Less corrosive with corrosion inhibitors. Higher cost.	MgCl ₂	-10°F	27 – 30%
Sand Sand is used as an abrasive for low temperature conditions on low-speed roads when chemicals are not effective. Sand provides temporary traction and only works when it is on top of ice.		Never melts – used for traction only	

Notes: ¹Use of calcium chloride and Pre-mix by itself is being used less and less. ²Only used in Districts 3 and 4 from FY11-FY15, and only used in District 3 in FY16.

MassDOT's standard road salt application rate is 240 lbs per lane-mile, which is generally considered to be the minimum needed to prevent snow and ice from bonding to the pavement under most conditions and especially when pavement temperatures range between 20 and 30°F (Clear Roads BMP Manual, 2015). The precise amount of deicing material needed in each application highly depends on the precipitation type and intensity, whether temperatures are falling or rising, road geometry (i.e., slopes and curves), pavement type, roadway drainage as well as the return interval for the chemical application. Other weather-related and

operational factors can also affect the relatively effectiveness and length of time between applications to prevent snow and ice from freezing to the pavement. Eventually, accumulated moisture from precipitation dilutes the concentration of the applied material making it less effective and the road more prone to freezing. Road salt is also much less effective when air and pavement temperatures are closer to 20°F as compared to near 32°F and rising. The time allowed between applications and prevent freezing can be highly variable as weather conditions change. Thus, the amount of deicing material applied over the course of a storm or season depends greatly on the number and rate of applications as well as the duration, timing, and number of precipitation events, as well as the prevailing temperatures, and the number of freeze/thaw cycles and the influence of drifting snow.

1.3.2 Pre-mix

Pre-mix is a commercially available product consisting of a 4:1 mix of granular sodium chloride and calcium chloride. Pre-mix has been primarily used in RSZs to reduce the amount of sodium inputs used near public and private water supply wells including surface water supplies (i.e., reservoirs). The sodium content in Pre-mix is approximately 20% less than that in road salt. The calcium chloride component of this blend also improves the deicing effectiveness at lower temperatures compared to regular road salt. Pre-mix however, is much more expensive than salt (i.e., \$200 per ton as compared to \$60-70 per ton, respectively). The calcium chloride component is also more corrosive to equipment and infrastructure and has a relatively short, shelf-life for storage because calcium chloride is hygroscopic (meaning attracts moisture). If not used within a certain time frame, it will become a solid block of material and un-useable. Due to the higher costs, storage limitations and the efficiencies gained through recent use of liquid deicers as well as other technologies, Pre-Mix is still being used on occasion as a supplement during very cold temperatures especially in the higher elevations in District 1 but in most Districts Pre-mix is being used less and less if at all.

Up until FY15, approximately 2,500 tons of Pre-mix was being used statewide on an average annual basis but in the last two years only District 1 has used it on a limited basis with approximately 601 tons used in FY17. For RSZ purposes, MassDOT believes it can achieve even greater sodium reductions than that achieved using Pre-mix with the increased use of pre-wetting and other anti-icing techniques as well as other technologies.

1.3.3 Sand

Sand has primarily been used to reduce the amount of salt applied in RSZs by using a 1:1 mixture of sand and salt for each application. Initially, it was hoped that the potential traction benefits of sand would offset the diminished capacity to prevent freezing due to less road salt being applied in each application. Over time, however, MassDOT has found that sand provides minimal traction benefits or, at best, it is very short-lived, because vehicular traffic quickly pulverizes the sand into smaller, rounded particles alleviating its abrasive properties for traction. Thus, sand provides minimal benefits in SICP operations. District personnel have found it to be extremely difficult to prevent snowpack buildup especially on the more heavily traveled roads when using the salt:sand application mix. Often times, more applications are needed in order to maintain the road.

Winter sand can also have adverse environmental impacts if not adequately contained and removed from roadways and drainage structures. Accumulated sand results in diminished flow capacity in drainage structures, siltation of stream beds in adjacent waterways, and increased pollutant loading. Residual sand on roadways also contributes to poor air quality related to particulate matter in the air. Despite its initial low purchase cost, the overall cost of sand is much higher when factoring in the post-winter cleanup costs associated with sweeping and disposal. The environmental impacts of using sand are discussed further in Chapter 2.

MassDOT has been more effective at reducing salt usage using anti-icing practices and other equipment upgrades as opposed to using sand in RSZs. The anti-icing practices have also resulted in better road surface conditions. As such, MassDOT plans to phase out the use of sand in RSZs. In recent years, MassDOT has reduced its statewide sand usage to around 20,000 tons per year compared to over 100,000 tons per year a decade or two ago. District 5 tends to use the most sand on a district basis because of the large number of RSZ lane-miles in the Cape Cod region. MassDOT has initiated a recent pilot test to evaluate whether a lower application rate of straight salt in a RSZ would perform better than the 1:1 mix of salt with sand. The study has only been done for one season but has shown early positive results. Much depends on temperature conditions and storm durations on an event by event basis. Using less sand not only reduces costs but also results in better road conditions and fewer environmental impacts.

1.3.4 Use of Liquid Deicers for Pre-Treatment and Pre-Wetting

Starting in 2011, MassDOT steadily increased its use of liquid deicers as part of anti-icing approach to pre-treat roads and pre-wet road salt to increase the effectiveness of road salt at the time of application. As shown in Table 1.5, MassDOT uses an average of 1.3 million gallons of liquid magnesium chloride ($MgCl_2$) per year during the last six years for pre-wetting and pre-treatment purposes. MassDOT also reduced the amount of calcium chloride used within the last six years. This material has been replaced with a corrosion-inhibited, liquid $MgCl_2$. Districts 1, 2, 4 and 5 also use a sodium chloride brine solution for pretreatment. The brine solution is cheaper than liquid $MgCl_2$ but not as effective at lower temperatures

For pretreatment purposes, liquid deicer is generally applied at a rate of 20 to 30 gallons per lane-mile using tanker trucks outfitted with spray nozzles. The salt concentration is generally much lower in liquid form than in solid form. For example, liquid $MgCl_2$ generally consists of 30% $MgCl_2$ and 70% water by weight while NaCl brine solution typically contains 23% sodium chloride by weight. At these concentrations, the amount of deicing material applied in a pretreatment application is generally in the range of 50 to 100 lbs per lane-mile or much lower than that applied when using a granular form. Although the initial pretreatment application is generally sufficient to prevent initial ice formation in the early stages of a storm and even delay the timing of the first road salt application eventually, the applied material becomes less effective due to dilution from melting precipitation. The length of time that the pretreatment application remains effective depends on the precipitation type and intensity and pavement temperatures. MassDOT has increased liquid deicer storage capacities in all districts to support anti-icing activities.

MassDOT has updated its equipment and contractor policies to require all spreaders to have pre-wetting equipment on board. Road salt is generally pre-wetted with liquid deicer at a rate of 8-10 gallons per ton just prior to being applied to the road. Pre-wetting road salt helps road salt adhere to the pavement because the salt is already activated or in semi-liquid state as it hits the pavement. A Michigan study found that pre-wetting salt eliminates approximately 30% of dry salt being wasted or lost off the pavement due to bounce and scatter of salt particles when applied to dry pavement (DeFoe, 1977).

1.3.5 Other Deicing Alternatives

MassDOT previously experimented with the use of Calcium Magnesium Acetate (CMA) in the 1990s on a stretch of Route 25, but found its performance was inferior to regular road salt in terms of preventing snow and ice from bonding to pavement. Furthermore, the cost for CMA generally ranges between \$1,200 to \$1,900

per ton or approximately 20 to 30 times greater than the price of road salt. CMA and other organic based deicer materials may have lower aquatic toxicities than chloride based deicers, but they pose other environmental risks with respect to nutrient inputs and high oxygen demand (MinnDOT, 2014). These other deicers are discussed in greater detail in Chapter 2.

1.4 Vehicle Washing Practices

MassDOT's vehicle washing policy (Env-01-22-1-000), specifies that outdoor vehicle washing using detergents or power washing equipment is not allowed and must be done indoors at designated depots that are either connected to a municipal sewer system, have a holding tank or a recycled wash water facility. Hired contractors are not allowed to wash vehicles at the depots. The SOP on vehicle washing is contained in the Facility Environmental Management Handbook which is posted on MassDOT's web site.

1.5 Annual Training Program

MassDOT has expanded its in-house training program for employees on an annual basis. MassDOT requires all employees involved in SICP activities (e.g., foremen, route coordinators and equipment operators) to attend annual operations training, which generally involves a half-day or full-day workshop. In 2016, each District had at least two operations training sessions. In addition, the Districts schedule separate "tailgate" training sessions at various depots for both state personnel and contractors. These "tailgate" training sessions are generally shorter in length and rotate around to different depots each year. In 2016, over twenty (20) tailgate training sessions were held in various district areas. More than 600 state personnel and approximately 300 contractors attended the tailgate training sessions. The training focused on equipment calibration and settings, MassDOT's policies and expectations, as well as safety and environmental considerations. As noted earlier, the current SICP Contractor Agreement includes a compensation stipend to attend these training sessions.

After each winter season, the District and Boston SICP Engineers typically convene for a one day training session to discuss operational and policy issues encountered during the season. These issues are typically incorporated into future training sessions.

1.5.1 Additional Training

Additional training is now available for those involved in SICP Operations through the state's government online training website, the Performance and Career Enhancement (PACE) Learning Management System. Example training lessons include Anti-Icing and Winter Maintenance, Computer Access to Road Weather Information, and Selecting Snow & Ice Control Materials to Mitigate Environmental Impacts (MassDOT, 2015).

MassDOT provides other environmental and personal safety training on various related topics. MassDOT also collaborates with the Baystate Roads Program to assist in training sessions for state and municipal personnel and periodically shares snow and ice related information for inclusion in its newsletters. The newsletter is disseminated to DPWs throughout the state and typically highlights the latest innovations and approaches to improve salt use efficiency as well as good housekeeping measures. The newsletter is made available online and provides links to additional resources.

1.6 Deicing Material Usage vs. Winter Severity

1.6.1 Introduction to the Winter Severity Index (WSI)

MassDOT uses a Winter Severity Index (WSI) to evaluate how changes in winter weather conditions affect annual road salt usage. The WSI methodology was initially developed by the State of Washington in the early 1990s as part of a Strategic Highway Research Project. The WSI provides a relative value on the level of winter weather severity and is calculated based on daily snowfall, daily minimum and maximum temperatures, and on the number of days with frost potential. The WSI value is calculated for each month and then averaged over the 5-month winter period (November-March) to provide a seasonal average. Comparing annual salt usage to the WSI value helps to explain how winter weather influences the amount of salt used from year to year.

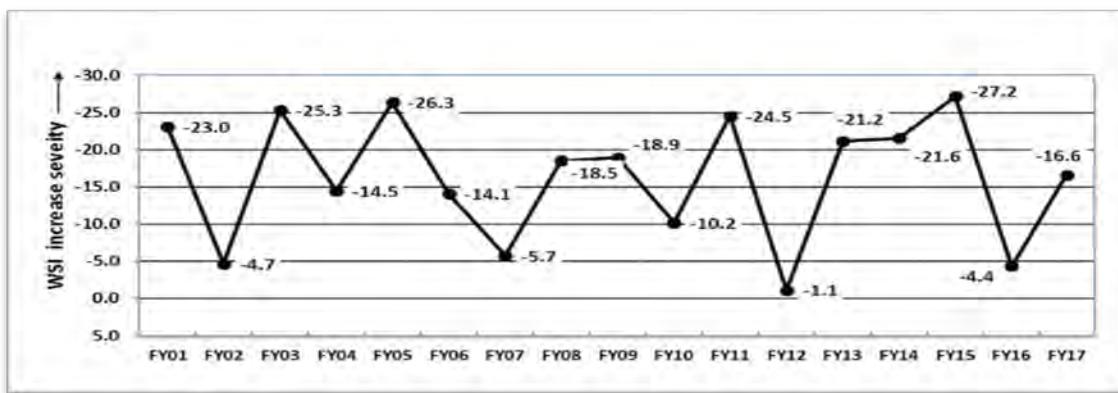
In prior public comments, commenters have suggested that MassDOT set a numerical target or goal to limit the amount of salt used each year. This is not practical since winter weather is highly variable from year to year and there is no feasible way to predict how much deicing material may be needed prior to each season. Use of the WSI does, however, allow for a reflective review to evaluate whether the amount of deicing material used was commensurate with the winter weather conditions based on a historical relationship of WSI to annual salt usage over a period of record as discussed below.

The WSI method can also be used to assess how equipment upgrades or other technology advances affect annual salt usage relative to previous years. By accounting for differences in winter severity, direct comparisons of deicing material usage can be made between years, especially years where newer equipment or practices have been implemented relative to older practices. The confidence of this comparison depends on the similarities in the period of record available using conventional and newer practices and the correlation between WSI values and annual salt usage during this period.

The annual road salt usage data from 2001 to 2010 represents the baseline period when conventional application methods were used, which is then compared to the road salt usage after FY11 (post-implementation) when several major policy and equipment changes were adopted. The changes include pre-wetting, use of closed-loop, ground-speed controllers, pre-treatment of roads and increased use of pavement sensors. The effects of these changes on annual salt usage are discussed in detail below.

1.6.2 Historical Summary of Winter Severity Index (WSI) Values

Figure 1.2 presents a comparison of average WSI values for each winter going back to 2001. The WSI values fluctuate greatly from year to year and even more so in the last seven years (FY11-FY17). The most severe winter (FY15) and the least severe winter (FY12) occurred in this same period. The FY15 winter had more than 100 inches of snowfall and unusually cold temperatures. The following winter of FY16 was the second mildest winter. In comparing years with similar WSI values between the baseline period (FY01-FY10) and the post-implementation period (FY11-FY16), the FY15 winter was most comparable to the FY03 and FY05 winters, and the FY11 winter was similar to FY01. The winters of FY16 and FY02 also had similar WSI values. These years represent good matchups for comparing salt usage data during the baseline and post-implementation periods.

Figure 1.2: Average Statewide Winter Severity Index (WSI) Values for FY01 – FY17

Notes: The winter period for each FY extends from November to end of March

Table 1.7 presents the same comparison of average statewide WSI values and relative ranking for the last 17 years. Lower WSI values indicate more severe conditions with the most severe winter (FY15) ranked as #1 and the least severe winter (FY12) ranked as #17. Despite wide variability from year to year, the average WSI values for the baseline period (FY01-FY10) and post-implementation period (FY11-FY17), are quite similar at -16.1 and -16.6, respectively. The last 7 years had two of the mildest winters and most severe winters in recent history.

Table 1.7: Summary and Ranking of the Annual Statewide WSI Value Over Last 17 Years

	Winter Season Fiscal year	Statewide Average WSI	Rank
Pre-Implementation	FY01	-23.0	5
	FY02	-4.7	15
	FY03	-25.3	3
	FY04	-14.5	11
	FY05	-26.3	2
	FY06	-14.1	12
	FY07	-5.7	14
	FY08	-18.5	9
	FY09	-18.9	8
	FY10	-10.2	13
FY01-FY10 Average		-16.1	
Post-Implementation	FY11	-24.5	4
	FY12	-1.1	17
	FY13	-21.2	7
	FY14	-21.6	6
	FY15	-27.2	1
	FY16	-4.4	16
	FY17	-16.6	10
FY11-FY17 Average		-16.6	

Notes: The WSI values are generally expressed as negative values and the lower values indicate greater winter severity.

1.6.3 Annual Road Salt Usage vs. Winter Severity Conditions During the Baseline Period

Figure 1.3 compares annual salt usage during the FY01 to FY10 baseline period to the WSI value for each year. As shown in the figure, the two variables are very closely related indicating that annual salt usage is highly dependent on winter weather conditions. During this baseline period, road salt was applied using conventional practices prior to the use of pre-wetting or pre-treatment practices or if they were used, it was

only in selected small areas. MassDOT's statewide average annual salt usage ranged from approximately 20 tons per lane-mile (ln-mi) during mild winters of FY02 and FY07 to as high as 50+ tons per ln-mi during relatively severe winters of FY03 and FY05.

Figure 1.3: Comparison of Annual Salt Use vs Winter Weather Severity WSI in the Baseline Period (FY01 to FY10)

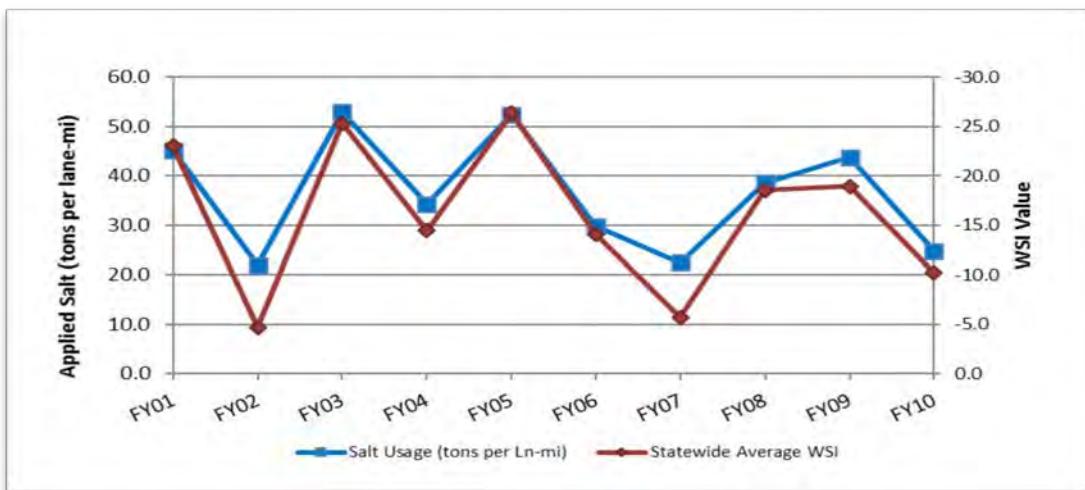
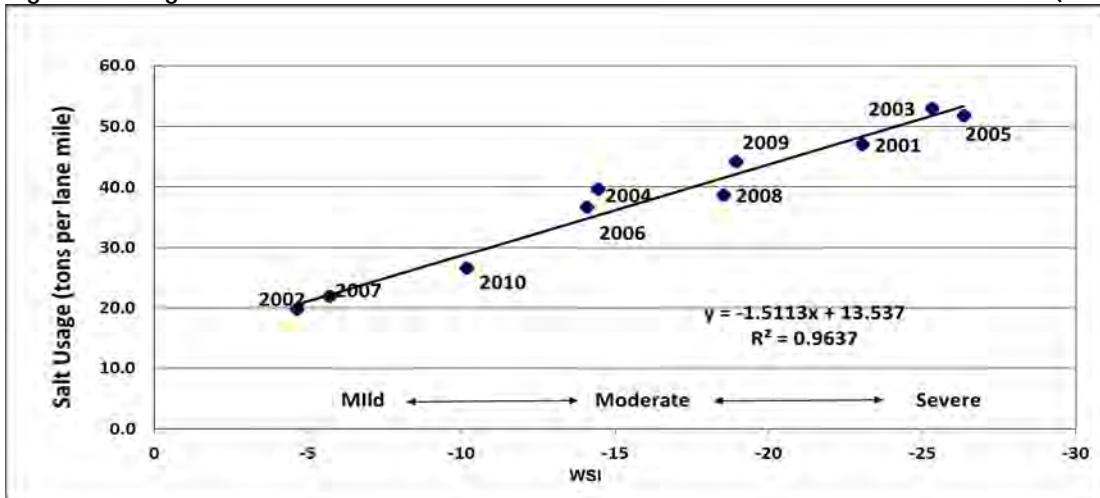


Figure 1.4 compares annual salt usage to the estimated WSI values for the FY01 to FY10 baseline period. The regression line and associated regression equation reveals how changes in winter weather severity values affect changes in annual salt usage. The more severe the winter, the higher the salt usage. The correlation coefficient (R^2) of 0.96 indicates that approximately 96% of the annual variability in salt usage is attributable to changes in winter weather severity, provided that the operational policies and application methods remained the same as was the case between 2001 and 2010. As discussed earlier, the anti-icing practices began in FY2011.

Figure 1.4: Regression Correlation of Annual Salt Use vs WSI Values in the Baseline Period (FY01 to FY10)



The regression equation, which expresses the relationship between annual salt usage and the WSI value over this 10-year period provides a means to predict future salt usage for a given WSI value while assuming the same application practices used during this baseline period are still in place. In other words, the regression equation can be used to estimate a predicted amount of salt usage assuming the same application methods used during the baseline period are still in use which can then be compared to the actual usage using the WSI value for the current winter with anti-icing practices and other advanced equipment in place. If actual usage is

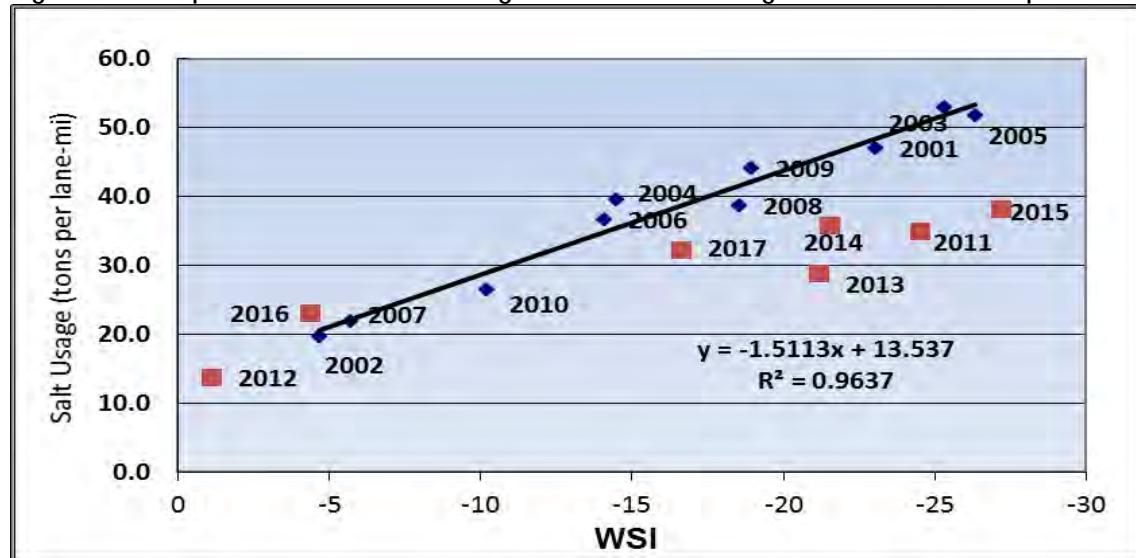
less than predicted (i.e., plotted below the regression line in Figure 1.4), then this indicates that less salt was used relative to what would have been used during the baseline period under the same WSI value. The difference or reduction in use is attributed to the anti-icing practices and equipment upgrades resulting in more efficient use compared to that used in the baseline period. This method is discussed further below.

1.6.4 The Effect of Anti-Icing and other Efficiency Measures on Annual Salt Use

As mentioned earlier, beginning in FY11, MassDOT initiated major policy and equipment changes including the pre-wetting of salt, closed-loop controllers, pre-treatment of roads, and increased use of pavement sensors.

Figure 1.5 compares annual salt usage for the last seven (7) years (shown in red) to that used in the 2001-10 baseline period (shown in blue). The 2011, 2013, 2014 and 2015 winters of the post-implementation period were all relatively severe winters and similar in severity to the winters of 2001, 2003, 2005, 2008 and 2009 in the baseline period. However, as shown on the figure, the annual salt usage during the more recent winters was much lower than that used in the previous years as represented by the regression line. On average, the annual salt usage in the last four years was 20 to 25% lower than that used in the baseline period under similar or even more severe winter weather conditions. The equipment upgrades and other technologies adopted in recent years have had a positive effect in reducing the overall amount of salt used on an annual basis. Salt usage in FY13 was approximately 35% less than that expected given the WSI value and what was used during the baseline period. In 2015, which was the most severe winter, the average annual statewide salt usage was 38.1 tons per lane-mile (ln-mi), or approximately 15 tons/ ln-mi less than that used in 2003 and 2005.

Figure 1.5: Comparison of Annual Salt Usage to WSI Values During Baseline and Post-Implementation Periods



Notes: Values indicated by blue diamonds represent annual salt usage (tons/ ln-mi) vs. WSI value during the baseline period whereas the red squares represent annual salt usage vs. WSI value during the post-implementation period.

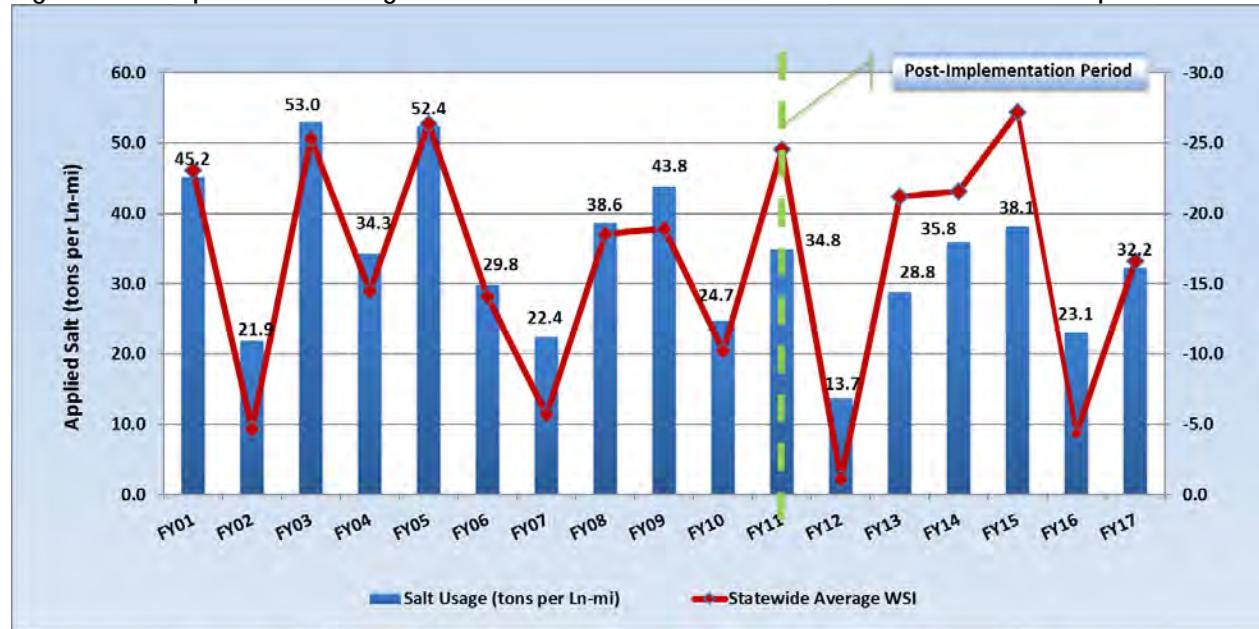
In the mild winters of 2012 and 2016, the equipment upgrades and anti-icing practices seem to have less of an effect on reducing salt usage or increasing efficiency compared to that used during the baseline period. As shown in Figure 1.5, the amount of road salt used in these winters was similar if not slightly higher than that used in the baseline period (regression line). The diminished effect may be due in part to several factors. First, the WSI methodology does not fully account for material applications needed during freezing rain and refreeze events as the calculation is weighted more heavily on snowfall and colder temperatures. Thus, in winters where

deicing material is applied in response to freezing rain events, the predicted salt usage will be underestimated. This was the case in 2012 and 2016, which had very little snow but several freezing rain events were noted by district personnel. Although the WSI methodology may not adequately predict salt usage in milder winters, this is not considered a major issue since road salt use is generally much lower and by as much as 50% or more in milder winters compared to normal or more severe winters. Minimizing salt use in more severe or higher use seasons using anti-icing and other efficiency measures is much more important.

Figure 1.6 presents a historical comparison of the average annual salt usage to the average statewide WSI value over the last 17 years. The relationship between the annual salt use to the WSI value in the baseline period differs from that in the post-implementation period (i.e., after FY11). Prior to FY11, the average annual salt usage (tons/lane-mile) was generally higher than the WSI value in each year. While, after FY11, except for the two mild winters, the annual salt usage was generally below the WSI values. This change indicates greater efficiency or performance by using less salt for the same or more severe winter weather conditions. This greater efficiency is attributed to the recent equipment and policy upgrades. As mentioned earlier, the FY15 winter was the most severe winter in the period of record, and yet the average annual salt usage was approximately 15 tons/ln-mi less than that used in FY03 and FY05, which were both slightly less severe winters.

On a statewide basis, approximately 125,000 fewer tons of road salt were used in FY15 compared to that used in FY03 and FY05. This represents an average reduction of approximately 25% and a material cost savings of approximately \$7.5 to \$8.7 million based on estimated salt purchase costs of \$60 to \$70 per ton, respectively.

Figure 1.6: Comparison of Average Annual Salt Use to WSI Values for the Baseline and Post-Implementation Periods



Notes: Numerical values on bar graphs represent actual annual salt usage in tons per lane-mile. Red line represents the statewide average WSI value.

1.6.5 District by District Comparison of Recent Salt Usage to Historical Usage

Table 1.8 presents a comparison of annual salt usage (tons per ln-mi) and relative WSI value for each district over the last seven (7) years. The table also provides a comparison of the average annual usage to the

historical average usage by district for the FY01-FY11 baseline period. The average WSI values were similar between the two periods for most districts (i.e., < 5% difference) except in District 5, which indicated a 45% increase in average winter severity in the last seven years compared to the previous 10 years. This increase is linked to several coastal winter storm events that have occurred in recent years.

In most districts, the average annual salt usage in the last 7 years was at least 20% less than the historical average from the previous 10 years. In Districts 1 and 4, the average annual salt use was more than 30% less than that used in the previous 10 years. District 6 was the only District indicating an increase in usage of approximately an 8% or a 2.8 tons per lane mile compared to the historical average. However, since District 6 did not exist prior to FY2011, the comparison to historical usage, which was based on District 4's usage, may be much less direct or not representative of the conditions in District 6. District 6 does maintain the Tobin Bridge and the Leonard P. Zakim Memorial Bridge as well as several large urban parkways in the Boston area, which may have different service and weather-related factors compared to conventional roadways.

Table 1.8: District by District Comparison of Recent Annual Salt Usage to Historical Average Usage (tons/lane-mile)

Fiscal Year	District 1		District 2		District 3		District 4		District 5		District 6		Statewide Average
	WSI	tons per ln-mi	WSI	tons per ln- mi	WSI	tons per ln-mi	WSI						
2011	-27.3	41.7	-18.1	27.8	-34.4	39.1	-25.0	35.2	-21.1	31.0	-21.4	40.3	-24.5
2012	-7.8	20.4	0.4	9.7	-4.7	15.2	1.2	10.9	1.3	15.9	2.9	10.6	-1.1
2013	-26.5	29.4	-11.2	24.2	-31.3	38.3	-22.6	23.1	-13.8	26.1	-21.7	34.6	-21.2
2014	-30.2	41.5	-19.9	29.0	-26.7	43.3	-17.7	25.7	-17.0	31.8	-17.7	58.3	-21.6
2015	-29.4	43.2	-20.7	37.9	-33.0	40.6	-29.7	25.8	-25.7	36.0	-24.7	61.6	-27.2
2016	-6.2	17.1	-1.0	18.7	-4.5	30.0	-1.6	16.2	-6.6	21.1	-3.1	39.7	-4.4
2017	-26.4	42.7	-15.8	34.4	-22.3	43.3	-13.4	23.4	-11.9	24.7	-9.9	38.2	-16.6
2001-10 Average	-20.8	49.1	-14.3	32.5	-21.3	47.0	-16.7	37.6	-9.3	36.4	-14.3	37.6*	-16.1
2011-17 Average	-22.0	33.7	-12.3	26.0	-22.4	35.7	-15.5	22.9	-13.5	26.6	-13.6	40.5	-16.6
Difference	-1.2	-15.4	2.0	-6.5	-1.1	-11.3	1.2	-14.7	-4.2	-9.8	0.6	2.8	-0.5
% Difference	6%	-31%	-14%	-20%	5%	-24%	-7%	-39%	45%	-27%	-4%	8%	3%
													-24%

Notes.*The historical average usage for District 6 was based on District 4's average annual usage on a per lane-mile basis for the 10-year baseline period.

1.6.6 Future Use of the WSI Methodology

MassDOT plans to continue using the WSI methodology as means to assess the performance/effectiveness of efficiency measures on annual salt usage through comparison to the baseline condition. Despite the fact that the WSI methodology does not account for all weather-related factors that may cause moisture accumulate and freeze on pavement and influence deicing demands, especially freezing rain events , as discussed above, the WSI method still provides a reasonable means to compare differences in current and historic salt data while factoring in changes in winter weather severity. This is particularly true given the high correlation coefficient ($R^2= 0.96$) between the WSI and annual salt usage for the baseline period. Other state transportation agencies have modified or attempted to modify the WSI approach to include other weather-

related variables, (e.g., freezing rain events, storm duration, or wind speeds) with varying success. However, the changes generally require additional weather details that is not consistently available or involves manual recording that is subjective in nature. Freezing rain is not universally recorded at all weather stations. The lack of consistency in the availability of data would make the WSI methodology more variable and difficult to use especially in retroactively updating the historical relationship between annual salt usage and the WSI values for the baseline period.

1.7 Stormwater Quality Treatment BMPs in RSZs

In review of the 2017 ESPR Work Plan, one commenter had inquired about whether MassDOT is using or has plans to use any structural stormwater treatment Best Management Practices (BMPs) to treat stormwater as a means of reducing sodium and chloride loading to the environment. MassDOT is not aware of any stormwater treatment BMPs that are effective in retaining or sequestering sodium and/or chloride from stormwater runoff as these constituents are highly soluble and dissolve in water. As discussed earlier, MassDOT has been focusing on source control measures to enhance the efficiency and effectiveness of road salt as well as other tools and technologies including better weather forecasting tools, application equipment, and plowing apparatus. MassDOT has also installed hundreds of structural stormwater BMPs along its roadways in recent years to capture and treat other stormwater related pollutants, such as total suspended solids and phosphorus.

MassDOT inspects and maintains its stormwater drainage system and related infrastructure (e.g., catch basins, culverts, culvert headwalls, drainage ditches, paved waterways) in accordance with MassDOT's Environmental Standard Operating Procedures (SOPs) (Env-01-35-1-000) *Routine Maintenance of Drainage Structures on Highway Division Roadways and Facilities*. These facilities are managed by the District Maintenance/Operations Engineer and are routinely inspected to determine if clean-out procedures are necessary.

1.8 Winter Maintenance Practices for Non-Roadway Facilities

MassDOT has many Park and Ride lots and Service/Rest Areas located throughout the Commonwealth (see Table 1.9 and Table 1.10 below). Winter maintenance activities in these areas are either contracted to local commercial providers or performed by MassDOT personnel on an as needed basis generally in the latter stages of winter events since these lots are at a lower priority level than the MassDOT roadways. Plowing represents the primary snow removal activity and chemical treatment is done more sparingly as these lots do not require the same level of service as the main roadways. Many Service/Rest Areas are also leased to commercial real estate entities who have assumed responsibility for snow and ice control as well.

Table 1.9: MassDOT Park & Ride Lots

District	Town	Location	Number of Spaces	Managing Agency
1	Charlton	Route 2, West of Route 112	75	MassDOT ¹
	Greenfield	18 Miner Street	64	MassDOT
	Ludlow	Route 21 at I-90, Exit 7	43	MassDOT
2	Northampton	Route 9, Bridge Street & Old Ferry Road	81	PVTA ²
	Northampton	VA Medical Center	Unknown	Unknown
	Whately	Route 5/10 at I-91, Exit 24	25	MassDOT
3	Auburn	Midstate Drive at I-90, Exit 10	135	MassDOT
	Berlin	Route 62 at I-495, Exit 26	45	MassDOT
	Framingham	Route 9 at I-90, Exit 12	120	MassDOT
	Millbury	Route 20 at I-90, Exit 10A	446	MassDOT
	Sturbridge	Route 131 at I-84, Exit 3 (Bethlehem Church)	50	MassDOT
4	Andover	Shawsheen Square (Route 28 and Route 133)	34	Other
	Andover	Dascomb Road at I-93, Exit 42	154	MassDOT
	Andover	Faith Church (Route 28 and Ballardvale Street)	60	MRTA ³
	Boxford	Middleton Road (rear of Firehouse)	15	Other
	Georgetown	27 East Main Street, Route 133, East of Georgetown Square	110	Other
	Methuen	Pelham Street at I-93, Exit 47	189	City of Methuen
	Newburyport	Route 113 at I-95, Exit 57	605	C&J Trailways
	Peabody	Route 1	150	MassPort ⁴
	Peabody	McVann Arena, Lowell Street	100	Other
	Topsfield	Park Street (Municipal Lot)	60	Other
5	Tyngsborough	Route 113 at Route 3, Exit 35	250	MassDOT
	Woburn	Off I-93, Exit 37C ARTC	375	MassPort ⁴
	Barnstable	Route 132 at Route 6, Exit 6	365	MassDOT
	Barnstable	Main Street (Hyannis)	182	CCRTA ⁵ , P&B ⁶
	Bourne	Meetinghouse Land at Routes 6 & 3, Exit 1	377	MassDOT
	Bridgewater	Route 104 at Route 24, Exit 15	60	MassDOT
	Falmouth	Depot Ave	51	Other
	Freetown	Gramp Dean Rd at North Main Street Route 24, Exit 10	33	MassDOT
	Harwich	Route 124 at Route 6, Exit 10	75	MassDOT
	Kingston	Route 3A at Route 3, Exit 10	100	P&B ⁶
6	Mattapoisett	North Street at I-195, Exit 19	80	MassDOT
	Middleborough	Town Hall (Nickerson Ave off Route 105)	100	Other
	New Bedford	Mt. Pleasant Street at Route 140, Exit 4	201	MassDOT
	Plymouth	Travel Plaza at Route 3, Exit 5 (Long Pond Rd)	200	MassDOT
	Raynham	Route 138 at I-495, Exit 8	79	Other
	Raynham	Route 138 at I-495, Exit 8 (Raynham Dog Track)	150	Bloom ⁷
	Rockland	Route 228 at Route 3, Exit 14	440	MassDOT
	Somerset	Route 6 at Route 138	80	Other
	Somerset	Route 103 at I-95, Exit 4	68	MassDOT
	Taunton	Silver City Galleria at Route 24, Exit 12	187	MassDOT
	Taunton	Oak Street (Bloom Terminal)	160	Other
	Wareham	Route 6/28 at Route 25, Exit 2	122	MassDOT
	Wareham	Mills Pond Diner	25	Other
	West Bridgewater	Route 106 at Route 24, Exit 16	185	MassDOT
	Braintree	Off I-93 at Exit 6, Route 37, Forbes Road	975	MassPort ⁴
6	Canton	Route 138 North of Blue Hill River Road	120	MassDOT
	Milton	Granite Ave at I-93, Exit 11	200	MassDOT
	Weston	Route 30 at Brown Street	100	MassDOT

Notes: ¹MassDOT = Massachusetts Department of Transportation; ²PVTA = Pioneer Valley Transit Authority; ³MRTA = Merrimack Valley Regional Transit Authority;

⁴MassPort = Massachusetts Port Authority; ⁵CCRTA = Cape Cod Regional Transit Authority; ⁶P&B = Plymouth & Brockton Street Railway Company; ⁷Bloom = Bloom Charter Service.

Table 1.10: MassDOT Travel Service Plazas and Tourist Information Centers

District	Town	Route and Direction	Services	Seasonal
1	Blandford	I-90 Eastbound	Service Plaza	No
	Lee	I-90 Westbound	Service Plaza	No
	Lee	I-90 Eastbound	Service Plaza	No
2	Greenfield	I-91 Northbound/Southbound (Exit 26)	Tourist Information Center, RMV	Yes
	Ludlow	I-90 Eastbound	Service Plaza	No
	Ludlow	I-90 Westbound	Service Plaza	No
3	Charlton	I-90 Eastbound	Service Plaza	No
	Charlton	I-90 Westbound	Service Plaza	No
	Framingham	I-90 Westbound	Service Plaza	No
	Lancaster	Route 2 Westbound	Tourist Information Center	No
	Natick	I-90 Eastbound	Service Plaza	No
	Westborough	I-90 Westbound	Service Plaza	No
4	Beverly	Route 128 Northbound	Service Plaza	No
	Chelmsford	I-495 Northbound	Tourist Information Center	Closed
	Chelmsford	I-495 Southbound	Rest Area	No
	Lexington	I-95 Northbound, Route 128/I-95	Service Plaza	No
	Merrimac	I-495 Southbound	Rest Area	No
5	Salisbury	I-95 Southbound	Tourist Information Center	No
	Barnstable	Route 6 Eastbound/Westbound (Exit 6)	Service Plaza	No
	Bridgewater	Route 24 Northbound	Service Plaza	No
	Mansfield	I-95 Northbound	Tourist Information Center	No
	Plymouth	Route 3 Northbound/Southbound (Exit 5)	Tourist Information Center/Service Plaza	No
	Plymouth	Route 25	Tourist Information Center	Yes
	Sagamore	Route 3 Northbound/Southbound (Exit 1A)	Tourist Information Center	No
6	Wareham	I-195 Eastbound	Tourist Information Center	Yes
	Yarmouth	Route 6 Eastbound	Tourist Information Center	Yes
	Blandford	I-90 Westbound	Service Plaza	No
	Newton	I-95 Southbound, Route 128/I-95	Service Plaza	No
	Westwood	I-95 Southbound, Route 128/I-95	Rest Area	No

1.9 Current and Future Initiatives

MassDOT has initiated several pilot studies to test the effectiveness and feasibility of newer tools and technologies. For example, a pilot study was initiated to evaluate whether electronic front loader scales that record the weight of material loaded in each spreader truck would provide better material usage data or could be used to verify usage data provided by closed-loop controllers. The study is in its preliminary stages and will require several winters to determine whether this tool warrants full-scale implementation.

MassDOT is also pilot testing whether lower or variable application rates of straight salt in select RSZs would be more effective at reducing salt use rather than using sand in a 1:1 salt-sand mix and still maintain reasonably safe road surfaces. The initial results have been positive, but the pilot test has only been done for one season and further testing and analysis is needed under a various storm and temperature conditions.

MassDOT is also pilot testing the use of AVL/GPS equipment to better track vehicle routes and material usage in the Kampoosa Bog area. MassDOT participates in various collaborative research programs under the Clear Roads Pooled-Funded Research Program. Eventually, MassDOT plans to have all hired and state-owned material spreader trucks be equipped with GPS/AVL technology in the next 4-5 years. This will allow tracking and reporting of material usage by route, event and on a watershed basis.

Current research topics that are being investigated under the Clear Roads Program include:

- Enhanced use and standardization of vehicle-mounted sensor equipment
- Utilizing GPS/AVL (global positioning system/automatic vehicle location) tracking and reporting
- Updated material application guidelines and best management practices (BMPs)
- Performance of SICP materials on porous or permeable pavements
- Enhanced/more effective snowplow operator and supervisor training

In addition, MassDOT continues to partner with the expertise of other federal and state organizations including the University of Massachusetts (UMass) Amherst Transportation Center and the US Geological Survey to perform research on its operations and the potential effects on the environment. MassDOT will continue to evaluate the feasibility and effectiveness of new technologies and tools as they become available and incorporate new information developed from ongoing research into future operations, as appropriate and as funding allows. MassDOT will continue to build on its recent progress on increasing the efficiency and effectiveness of its SICP while minimizing potential adverse effects on the environment and infrastructure. Section 7 of this ESPR provides a more complete listing of planned future operational and equipment initiatives.

2

Environmental Resource Protection and Remediation

2.1 Introduction

MassDOT has established a Salt Remediation Program and a Reduced Salt Zone (RSZ Policy to help protect environmental resources that may be affected by its winter maintenance activities. This chapter provides a discussion of the potential effects of salt use on environmental resources and the various policy changes and Best Management Practices (BMPs) that MassDOT had used to mitigate these effects. An update on reported sodium and chloride levels in the various Public Water Supplies (PWS) located throughout the Commonwealth is also provided along with an update of MassDOT's coordination efforts with the various PWS. A description of the various sensitive environmental resources that have been identified throughout state is also provided.

Following review of the 2017 ESPR Work Plan, MassDEP expressed several comments on the potential adverse impacts that deicing chemical usage may have on environmental resources (see comments in **Appendix A**). MassDEP suggested that MassDOT revise its remediation policy to use MassDEP's drinking water health guidance level of 20 mg/L for sodium as the threshold to trigger remedial measures for private or public wells.

MassDEP also expressed concerns that MassDOT's RSZ Policy, which requires PWS to provide monthly sodium and chloride data for raw water and treated water as a precondition to remedial actions, was too burdensome for well owners. As discussed further below, the request for monthly data prior to the establishment of a RSZ is essential for a variety of reasons. Private well owners who file Salt Remediation Program applications are only asked to provide one month's worth of data to determine if they meet the program's criteria. Once MassDOT determines that the complaint warrants further investigation, MassDOT will cover additional sampling costs.

MassDEP also commented that the previous ESPRs or GEIRs did not adequately document the successes of the Salt Remediation Program. MassDEP suggested that the number of remediation complaints and responses that have occurred over the last 20 years be summarized in the 2017 ESPR as well as the nature of the public outreach efforts used to promote public awareness of the Salt Remediation Program be fully described in the next ESPR. A status update of the various remediation cases investigated over the years as well as an update on MassDOT's efforts to increase public awareness of its Salt Remediation Program is provided in Section 2.2.

2.2 Reduced Salt Zone (RSZ) Program Update

MassDOT currently has sixty-two (62) RSZs statewide which are located primarily in Zone II Wellhead Protection Areas (i.e., contributing areas of PWS wells). These RSZs are in areas with documented elevated sodium levels and site-specific conditions (based on the results of a hydro-geological investigation) that indicate that the elevated sodium levels are due, at least in part, to MassDOT's deicing practices. The following describes MassDOT's policy on establishing RSZs and the potential health benefits in lowering or preventing increases in sodium levels in public or private water supplies.

2.2.1 RSZ Designation Process

Once a written request for an RSZ has been received from a water supplier and/or a private homeowner, MassDOT will respond with either a written request for additional water quality data or will initiate a site investigation in accordance with MassDOT's RSZ Policy (ENV-01-30-1-000). If limited water quality data is provided in the request, well owners are asked to provide sodium and chloride data for the following reasons:

- 1) Sodium and chloride data collected throughout the year helps to validate whether road salt is the primary cause of elevated sodium and chloride levels in the respective water supply.
- 2) The data enables MassDOT to assess how effective existing or proposed measures may be in lowering sodium levels; as well as helps to inform decisions on whether an existing RSZ should be expanded, modified or eliminated based on trends in the sodium and chloride data.
- 3) Establishing and maintaining a RSZ has major cost implications and, thus, MassDOT must ensure that it does not expend funds unnecessarily if a RSZ is not going to measurably improve water quality due to other sources and various site-specific factors as discussed in greater detail below.

Having historical water quality data for a particular well helps to determine whether MassDOT's operations or other sources are causing the increased sodium levels in the respective well(s) and helps to define the potential scope of a site investigation, if needed. To be fiscally prudent, it is important that MassDOT investigate and evaluate the various local conditions and factors that may affect sodium levels in the well. Otherwise, implementing a RSZ may not result in any meaningful benefits and could expend taxpayer dollars unnecessarily. As discussed below, maintaining RSZs adds considerable costs due to the increased personnel to monitor road surface conditions between applications as well as the post-season cleanup cost of applied sand.

No new RSZs have been established in the last ten years largely because MassDOT has become more effective in reducing road salt use by focusing on anti-icing practices rather than using the sand:salt application mix. Anti-icing represents a more proactive approach of using liquid deicers to pretreat roads and prewet salt early in the storm event to prevent snow and ice pack from forming on the pavement. Going forward, MassDOT believes it will be more successful in reducing road salt use by expanding and broadening its use of liquid deicers and other more precise application technologies rather than relying on sand or granular materials to reduce salt use in RSZs or other environmentally sensitive areas. This is discussed further in the Section 2.3.3.

2.2.2 Existing RSZs

Table 2.1 presents a summary of the various RSZs, their associated route numbers, roadway mileage, and lane-mileage within each District. A detailed description of the roadway segments and materials used in each of these RSZs is contained in MassDOT's Reduced Salt Policy, (HMD-01-01-1-000). The number of total roadway miles and lane-miles within the designated RSZs consists of approximately 624 roadway miles and 1,752 lane-miles. This represents a little more than 11% of the total lane-mileage maintained by MassDOT. Some of these RSZ segments may be adjacent to each other on the same roadway but are defined as separate segments because of the plow route boundaries.

Table 2.1: Summary of MassDOT Reduced Salt Zones by District¹

District	No. of RSZs	Routes	Total Roadway Miles	Total Lane Miles
1	4	Routes 8/ 9/ 112	4.7	18.1
2	8	Routes 2/ 9/ 63/ 202	27.2	99.2
3	8	Routes 12/ 20/ 70/ 110	25.3	133.1
4	17	Routes 2/ 2A/ 3/ 3A/ 4/ 95/ 110/ 128/ 129/ I-93/ I-95 / I-495, Route 1/95 Interchange, Lowell Connector	193.4	404.5
5	23	Routes 1/ 6/ 6A/ 18/ 25/ 28/ 130/ 140/ I-495 /I-295	359.0	1002.6
6	2	Routes 20/ 128	14.2	94.5
Totals	62		623.9	1,752

Notes: ¹Data obtained from MassDOT Environmental SOP HMD-01-01-1-000.

Due to greater roadway and population densities as well as more businesses and institutions being served by public wells in the more urbanized areas of the State, most of the RSZs are located in Districts 4 and 5. District 4 has approximately 193 road miles or 404.5 lane-miles in various RSZs. One of the larger RSZs in District 4 consists of approximately 67.2 lane-miles of Route 128/I-95 in the Towns of Lexington and Waltham, which are within the watershed of the Cambridge water supply reservoirs. Approximately 73 lane-miles of I-95 in Boxford and Georgetown was established as an RSZ to minimize sodium levels in various private wells located near I-95. Approximately 50.4 lane-miles of Routes 3 and 3A in Chelmsford and North Chelmsford were established to minimize increases in sodium levels in the nearby municipal wells serving these communities. The northerly section of Route 128/I-95 in the Lynnfield/Peabody area (63.2 lane-miles) is another large RSZ established to protect the water supply for an industrial facility, which requires ultrapure water for manufacturing.

District 5 has over 1,000 lane-miles of RSZs primarily because all the state-maintained roadways on Cape Cod including Routes 6, 6A, 28, and 28A are designated as RSZs. Roadways in the Cape Cod region account for approximately 803 lane-miles of the RSZs in District 5. However, in review of the sodium data in PWS in the Cape Cod region, discussed in Section 2.4, most PWS near a MassDOT road have relatively low sodium levels.

A section of I-495 in Middleboro between Interchanges 3 and 6 (approximately 43.9 lane-miles) and a parallel section of Route 28 (approximately 21.3 lane miles) are also designated RSZs to protect the Middleboro water supply wells. Portions of Routes 1, I-95, and I-295 in Attleboro and North Attleboro are also designated RSZs as well as portions of Routes 18, 28, and 140 in the Avon, Freetown, Lakeville, and Taunton area.

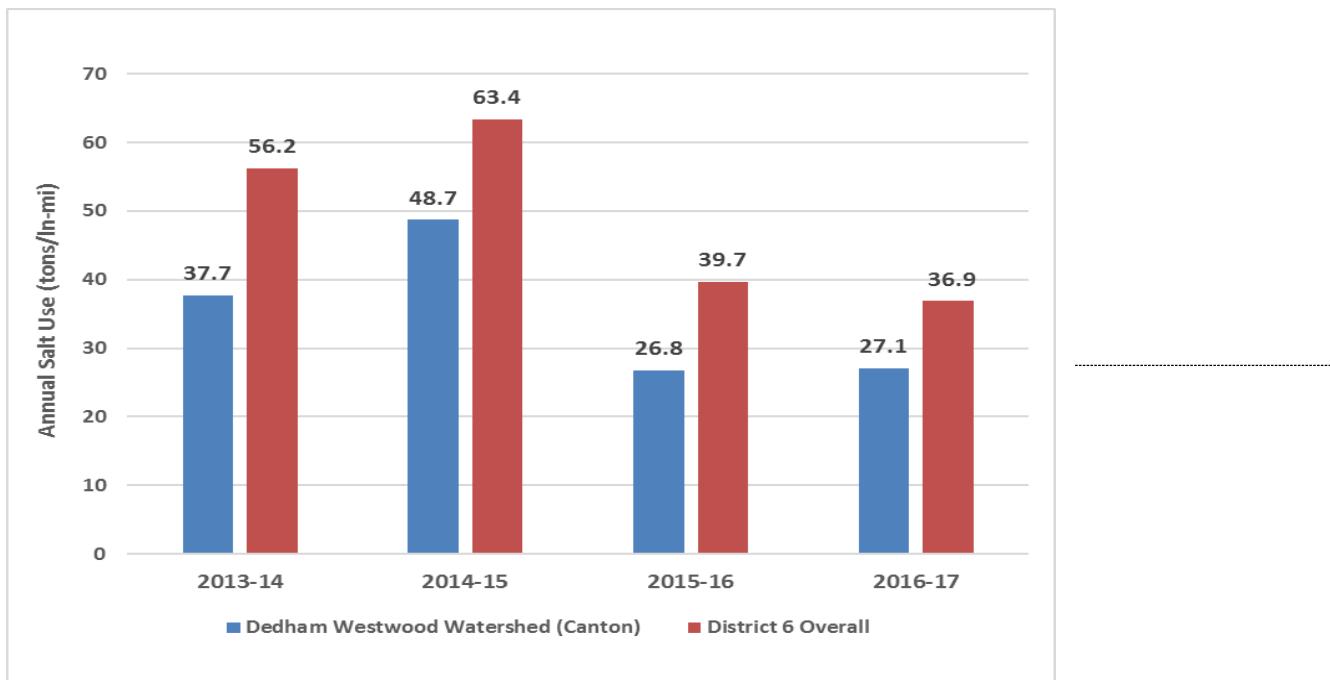
2.2.3 Snow & Ice Control Operational Practices in RSZs

Historically, the primary method of reducing the amount of sodium based deicer used in RSZs relied on using a 1:1 mixture of sand with road salt applied at the typical rate of 240 pounds per lane-mile in accordance with MassDOT SICP Policy. The 50:50 mix of salt and sand theoretically resulted in roughly a 40% reduction in the amount of sodium in each application (Note: there is a minor amount of salt in the sand as well). However, because only 120 pounds or half the typical amount of deicing material is applied when using a salt:sand mix, snow and ice personnel have found it much more difficult to maintain reasonably safe road conditions as compared to regularly-treated roadways. During cold winters, in particular, it is often much more difficult to prevent snow and ice from bonding to the pavement, especially on high traffic volume roads. To compensate for the reduced effectiveness, district personnel have found that additional applications are often needed. Once snow and ice bonds to the pavement, it requires even more chemical treatment to break up the snowpack and return to bare pavement. In the end, especially during severe winters, the amount of road salt used in a RSZ can often be similar to that used on regularly-treated roads because of the added applications.

Not only is the use of sand in RSZs not very effective in reducing salt use but it also adds costs due to the additional personnel and equipment needed for road monitoring, repeat applications and post-season cleanup. As reported in the 2012 ESPR, MassDOT estimates that maintaining an RSZ costs an additional \$2,000 per lane-mile per year, on average, compared to a conventionally-treated roadway, primarily because of the added equipment and personal costs. To maintain approximately 1,752 lane miles of RSZs statewide, MassDOT spends an additional \$3.5 million a year, on average. In addition, the use of sand results in other environmental impacts with respect to sedimentation and phosphorus loading.

Alternatively, MassDOT has been more successful in reducing salt usage through enhancing and broadening its use of anti-icing practices and equipment upgrades. MassDOT has already reduced its statewide annual usage of road salt by approximately 24%, on average, and has observed average reduction as high as 36% depending on the winter. MassDOT plans to continue to enhance its current operations and add new tools to reduce salt usage statewide while eliminating the use of sand and essentially the RSZ Program. This would not only reduce salt usage but would likely be more cost effective, provide more consistent road conditions and eliminate the environmental impacts associated with sand.

Recently, MassDOT initiated a pilot study of equipping material spreaders with AVL/GPS technology in the Dedham-Westwood Water District (DWWD) area in response to their request for a RSZ. As shown in Figure 2.1 below, MassDOT has reduced its annual salt usage in the last four winter seasons on roadways within the DWWD area by nearly 30%, on average, compared to what was used on other District 6 roadways. This level of reduction is generally much better than what would have been accomplished using the sand:salt mix or even Pre-mix material, which is much more expensive. Use of AVL/GPS technology will be expanded in this area in 2017/18 to include additional equipment. MassDOT has not received any updated water quality data to determine whether the recent salt use reduction have changed the trajectory of sodium levels in the wells. It is also possible that deicing applications on other paved areas (e.g., parking lots) in the area are influencing sodium levels in these wells as well.

Figure 2.1: Road Salt Usage in the DWWD Wellhead Protection Area vs Other District 6 Roads

2.2.4 A Review of Similar Practices in other States

MassDOT queried snow and ice control personnel from other Snow Belt states using a web-based snow and ice management *listserve* to determine whether other states utilize RSZs or other similar low or no salt practices in designated areas to protect water supplies or other environmentally sensitive areas.

Eighteen states responded to the query with ten states reported that they have no specific salt reduction policies or designated sensitive areas where salt applications are reduced. Eight states indicated that they utilize some form of reduced salt management in select areas, with two states (Michigan and West Virginia) reporting that reduced salt usage is mostly around major bridges, while two other states (Wyoming and Vermont) reported reducing the amount of salt applied around certain select rivers or streams. Four of the remaining other states (New York, Oregon, Arizona, and Washington) reported recently initiating pilot studies or monitoring programs to assess current practices either on a statewide or select area basis to identify how salt can be applied more efficiently. In general, it seems that very few states, especially in the Northeast Region, have any formal or established RSZ practices, which makes MassDOT relatively unique in the number and extent of RSZs currently included in their program.

2.3 Salt Remediation Program

The Environmental Services Section of MassDOT's Highway Division administers the Salt Remediation Program, which process and investigate complaints from private well owners and public water suppliers whose water supplies are experiencing elevated sodium concentrations. As outlined in MassDOT's Environmental Standard Operating Procedures (SOP) (ENV-01-30-1-000), a completed salt remediation application must be submitted along with water quality data to the jurisdictional District Highway Director. For qualified claims, the Environmental Services Section will conduct an initial site visit to determine whether further investigations are warranted. Since 2004, MassDOT has maintained an Interagency Service Agreement with the UMASS Engineering Department to perform field investigations and hydro-geological studies to assess and remediate elevated salt concentration complaint issues. If MassDOT's road salt use appears to be a potential source, additional sampling will be conducted to confirm elevated levels of sodium and chloride. To initiate a field investigation, a well owner must meet one of the following conditions:

- A resident is on a documented sodium restricted diet of less than 1000 mg/d and the sodium concentration in the water supply exceeds 20 mg/L, or;
- A resident is on a documented sodium restricted diet of less than 2000 mg/d and the sodium concentration in the water supply exceeds 40 mg/L, or;
- The chloride concentration in a domestic supply well exceeds 250 mg/L

For residents on a prescribed sodium restricted diet or if chloride concentrations exceed 500 mg/L, MassDOT will provide bottled water as an interim measure during the investigation. MassDOT will implement remedial measures if the investigation shows that the elevated salt concentrations are primarily due to MassDOT's SICP activities. In most cases, MassDOT will collect water samples for up to 12 months on behalf of the private well owner. The data are compared to historical salt application information to determine whether MassDOT's deicing chemical use is a likely significant source of elevated salt concentrations in the water supply.

MassDOT has posted various informational materials regarding its Salt Remediation Program on its website including application forms and contact information. More information can be found online at:
<https://www.massdot.state.ma.us/highway/Departments/EnvironmentalServices/SaltRemediationProgram.aspx>

On average, MassDOT spends approximately \$1.5 million per year on its Salt Remediation Program to investigate and remediate complaints. The annual costs vary depending on the number of cases and the geographic extent of the affected areas. Most of the complaint cases and remediation activity have been related to private wells associated with individual residences. Remediation measures typically include replacement or rehabilitation of an existing well, connecting the property to a PWS system or installation of a reverse osmosis (RO) treatment system. Installing a whole house RO system, however, is usually used as a last resort as these water treatment systems are expensive and require more effort to operate and maintain. In certain locations, where there may be a cluster of homes involved, RSZs have been established in addition to installing replacement wells as the potential for municipal water sources are limited. A few cases have involved public wells associated with various businesses, schools, or other public facilities.

Table 2.2 summarizes the salt remediation cases received, investigated and remediated in each District since 2000. During this period, a total of 201 remediation claims were received. On, average, approximately twelve (12) remediation claims are received each year and has ranged from a low of five (5) cases in 2005 and 2006 to a high of twenty-three (23) cases in 2004. In the last five (5) years, fifty-six (56) claims were received compared to sixty-eight (68) claims in the previous five years, indicating a potential declining trend. In 2015 and 2016, only nine (9) and seven (7) claims were received, respectively. All but fifteen (15) cases have been remediated and closed, with the remaining open cases still in various stages of investigation or remediation.

Table 2.2: Summary of Closed and Ongoing Salt Remediation Cases by District

District	Total Cases (1)	Open Cases (1)	Closed	Type of Well	Towns ²
1	34 (12)	3 (2)	31	Private	Blandford, Clarksburg, Great Barrington, Otis, Sandisfield, West Stockbridge, Zorn
2	44 (12)	3 (3)	41	Private	Orange, Palmer, Pelham, Brimfield
3	83 (30)	6 (6)	77	Private	Ashby, Charlton, Grafton, Groton, Hopkinton, Lancaster, Mendon, Northborough, Sturbridge, Upton, Uxbridge, Westford
4	31 (15)	2 (2)	29	Private	Boxford, Lincoln, Tyngsboro
5	9 (1)	1 (1)	8	Private	North Attleboro, Rehoboth, Wrentham
6	0	0	0	na ³	na ³
Total	201 (56)	15 (14)	186		

Notes: ¹ Number in () represent # of cases within the last 5 years.

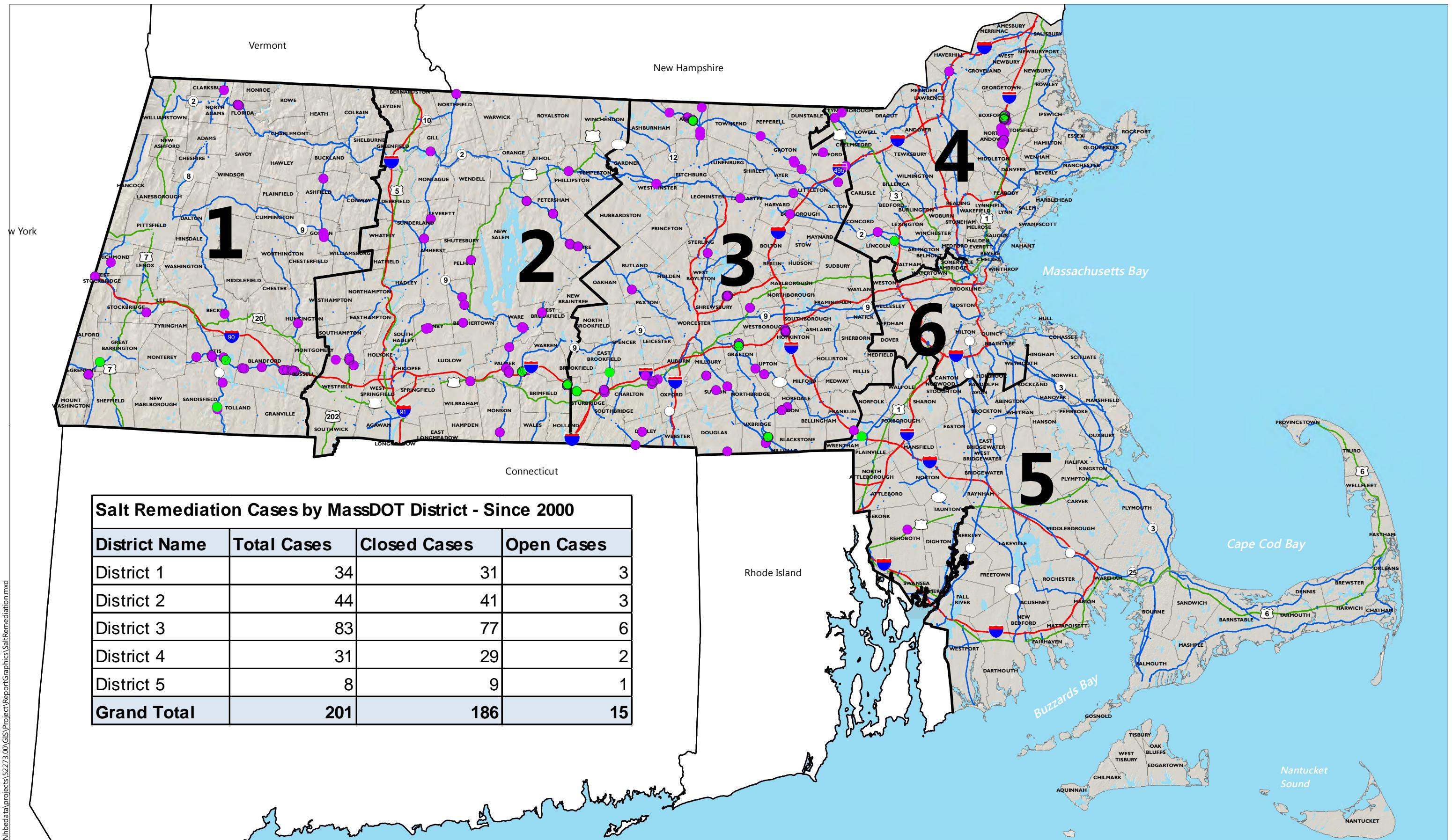
² Towns listed pertain to the open cases only.

³ No current/open cases in database.

Overall, the Salt Remediation Program has been successful in providing potable water with reduced sodium levels for private water supply complaint cases after remedial measures have been implemented. In a few instances where remediation measures were not successful in reducing sodium concentrations, MassDOT continues to work with the affected homeowner or PWS to identify the primary sources and potential solutions that MassDOT could implement to reduce sodium concentrations.

Figure 2.2 provides a map of the salt remediation case locations and status. Many are in the rural areas of Districts 1, 2 and 3 because most homes and businesses are served by private wells in these areas.

MassDEP suggested that MassDOT install groundwater monitoring wells along roadways or in known contributing wellhead protection zones of public wells. Although it is recognized that having more data is generally better than less, the significant cost to install and maintain these wells would not be the best use of taxpayer dollars, especially since PWS are already testing their water on a regular basis. Instead, it may be more cost-effective to rely on data already being collected by others to identify areas with declining water quality conditions. Once these areas are at least preliminarily identified, financial resources can be more effectively utilized to prioritize and implement equipment upgrades and other efficiency measures to reduce overall road salt usage, to the extent feasible.



Since 2000

- Open (15)
- Closed (186)

Note: Not all cases are visible due to low resolution and map scale.



2017 Snow & Ice Control ESPR

MassDOT

Figure 2-2
Salt Remediation Case and
Status Locations

2.4 Sodium and Chloride Data in Public Water Supplies

In their review of the 2017 Draft ESPR Work Plan, MassDEP requested that MassDOT provide an update on the reported sodium and chloride levels in Public Water Supplies (PWS) located within a 0.5-mile of a MassDOT road. The 2012 ESPR conducted a similar evaluation but focused only on sodium levels and on community and non-transient, non-community PWS located within a 0.5-mile of a MassDOT road. Per MassDEP's request, the analyses summarized below includes all PWS with at least one source within a 0.5-mile of a MassDOT roadway. The number or percentage of PWS with sodium levels above MassDEP's drinking water health guideline of 20 mg/L and/or above the EPA health guidance level of 60 mg/L was evaluated. A regression analysis was also conducted to assess the relationship or correlation between sodium levels in PWS and distance to a MassDOT roadway. In addition, a historical review of sodium levels in various municipal water supplies is also presented. MassDEP also expressed concerns about the potential effect that increasing chloride levels may have on the corrosivity of water supply infrastructure. Chloride levels in PWS throughout the state were also analyzed based on reported data compiled by the MassDEP Drinking Water Program through August 2016.

MassDEP set a health guidance level of 20 mg/L for sodium (see MassDEP Drinking Water Regulations, 310 CMR 22.16A), which is an advisory level for individuals that are on a physician prescribed "low-salt" diet to limit their sodium intake to no more than 500 mg per day. This guidance is based on EPA recommendations for sodium levels in drinking water (EPA, 2003). As described further below, if the 20 mg/L level is exceeded, MassDEP requires PWS to test for sodium at prescribed intervals and report detected concentrations to their local Boards of Health, the Massachusetts Department of Health, and MassDEP (MassDEP, 2006). Treatment of elevated levels is not specifically required.

MassDEP's guidance level is based on EPA's original guidance of 20 mg/L established in 1998 when sodium was placed on potential Contaminant Candidates List for further study. EPA had set the guidance level to limit the daily sodium intake from drinking water to be no more than 40 mg or less than 10% of the daily total intake if people are on physician prescribed sodium restricted diets of no more than 500 mg per day.

In 2003, EPA updated this health guidance level for sodium in drinking water based on additional research and in recognition that the principal source of sodium was from food consumption rather than water consumption. The revised guidance recommends sodium levels in drinking water be no greater than 60 mg/L to avoid esthetic effects associated with taste. Drinking water below this level is not likely to be perceived as salty by most individuals and would only contribute approximately 5% of a recommended dietary goal of no more than 2400 mg of sodium per day if tap water is consumed at two liters per day. The Food and Drug Administration has reported that most Americans tend to consume between 4,000 and 6,000 mg of sodium per day with most of this coming from food consumption (EPA, 2003).

2.4.1 MassDEP Sodium and Chloride Testing Regulations for PWS

Per MassDEP Drinking Water Regulations (310 CMR 22.00), a PWS is defined as a water supply system that has 15 or more connections or serves at least 25 individuals, on average, on a daily basis for at least 60 days out of the year. There are three categories of PWS depending on the populations they serve which include: (1) community PWS, which generally serve the same people each day typically in a residential setting (e.g. municipal systems, condominiums or homeowner associations), (2) non-transient, non-community (NTNC) PWS, which typically serve the same population each day but in a non-residential setting (e.g., schools,

businesses, office complexes, day care, etc.) and (3) transient, non-community (NC) PWS, which generally serve a transient population of usually different people each day (e.g., restaurants, retail stores, golf courses, etc.).

A PWS can include both groundwater and surface water supply sources. As of January 1, 1993, all PWS are required to test for sodium at each entry point into the water distribution system and report the results to the MassDEP Drinking Water Division (310 CMR Sec 22.06A.). For PWS using groundwater, the required sampling frequency is once every three years, while those using surface water sources (including PWS with combined sources of surface water and groundwater), are required to sample and report sodium levels annually. MassDEP also maintains a secondary drinking water standard for chloride at 250 mg/L to avoid issues with aesthetics and taste. Testing for chloride is not required but generally recommended especially if sodium levels are elevated.

2.4.2 Analysis of Sodium Data in Public Water Supplies

MassDEP's database of reported sodium and chloride data in Public Water Supplies (PWS) (as of August 2016) contains 16,346 records of sodium sampling results and 3,594 chloride sampling results going back to 1993. The reported sodium data is associated with a total of 1,821 different PWS. Of these, a majority or 1,030 are non-community PWS serving a transient population while another 487 are categorized as community PWS, and 304 are categorized as non-transient, non-community PWS. The latter generally service non-residential settings such as schools, office buildings, day care establishments, etc. Many larger community PWS have multiple readings for various years and/or sources including different wells and/or surface water sources or a combination of both. Generally, if one source has elevated sodium levels, then all sources in the system are tested and reported to MassDEP. The sampling location for each PWS may include raw water, multiple sources and/or finished treated water. The potential mixing or blending of sources or whether or not sources are currently active or inactive was not evaluated as part of this analysis.

Using MassDOT's GIS Road Inventory and the PWS source location information, a total of 946 PWS were identified as having at least one source within a 0.5-mile of a MassDOT roadway. While another 817 PWS were identified as being outside of a 0.5-mile radius from a MassDOT roadway. Distances to a roadway could not be determined for another 202 PWS because there was no location information included in the data base. Of the 946 PWS within a 0.5-mile of a MassDOT roadway, 282 are community PWS, 151 are non-community, non-transient PWS and 513 are non-community, transient PWS. Per MassDEP's request, all three categories of PWS were included in this analysis of sodium and chloride levels as described below.

Table 2.3 compares average and maximum reported sodium concentrations above certain concentration thresholds for PWS that are located inside and outside a 0.5-mile radius of a MassDOT roadway. The analysis focused on the most recent sodium data collected between 2012 and 2016 as reported for each PWS. As such, a total of 867 and 751 PWS that are located within and beyond 0.5-mile of MassDOT roadway, respectively, that had reported sodium data from the last five (5) years (2012-2016).

The results indicate that 52% of the PWS located within a 0.5-mile of a MassDOT road have an average sodium concentration above 20 mg/L compared to 38% of the PWS located more than a 0.5-mile from a MassDOT road. Approximately 18% of the PWS located within a 0.5-mile from a MassDOT road have an average concentration above 60 mg/L as compared to 8% of the PWS located more than a 0.5-mile from a MassDOT road. The percentage of PWS that had an average sodium concentrations above 100 mg/L differs from 3% to 9% when comparing data from PWS located beyond and within a 0.5-mile of a MassDOT road, respectively.

In review of maximum reported sodium concentrations, 55% for PWS located within a 0.5-mile of a MassDOT road had a maximum sodium concentration above 20 mg/L compared to 43% of the PWS located more than a 0.5 mile from a MassDOT road. For PWS with a maximum reported sodium concentration above 60 mg/l, the difference was 25% and 15% for PWS located within and outside a 0.5-mile of a MassDOT road, respectively. Similarly, the percentage of PWS that had a reported maximum sodium concentration above 100 mg/L was approximately 18% and 8% for PWS located within and outside a 0.5-mile of a MassDOT road, respectively,

Table 2.3: Comparison of Average and Maximum Reported Sodium Concentrations in PWS Located Within and Beyond of a 0.5-mile Radius of a MassDOT Road

Sodium Conc. (mg/L)	Average Reported Na Conc. ¹ (mg/L)				Maximum Reported Na Conc. (mg/L)			
	PWS within a 0.5 mile ²	PWS outside a 0.5 mile	PWS within a 0.5 mile ²	PWS outside a 0.5 mile	No. of PWS	% of Total	No. of PWS	% of Total
<= 20	417	48%	468	62%	387	45%	428	57%
>20	450	52%	283	38%	480	55%	323	43%
> 40	258	30%	127	17%	309	36%	170	23%
> 60	154	18%	63	8%	214	25%	110	15%
> 80	101	12%	35	5%	154	18%	58	8%
> 100	74	9%	25	3%	121	14%	38	5%
> 120	56	7%	19	3%	95	11%	31	4%
> 150	40	5%	14	2%	64	7%	23	3%
> 200	22	2.5%	9	1%	44	5%	16	2%
> 300	6	0.7%	4	1%	19	2%	7	1%
> 500	2	0.2%	1	0.1%	8	1%	3	0.2%
>1000	1	0.1%	0	0.0%	3	0.3%	1	0.1%
>1500	0	0%	--	--	1	0.1%	1	0.1%
>2500	--	--	--	--	0	0%	1	0.1%
>5000	--	--	--	--	--	--	1	0.1%
Totals	867		751		867		751	

Notes: ¹ The average concentration represents an average Na conc using data from all sources for each PWS reported between 2012 and 2016. ²Includes all PWS that have at least one source within a 0.5 mile of a MassDOT roadway based on 2010 MassDOT Road Inventory GIS layer and includes all categories of PWS including community, non-transient non-community (NTNC), and transient, non-community (NC) PWS.

Although PWS located closer to a MassDOT road had a higher percentage of PWS with average or maximum sodium concentrations above the guidance thresholds compared to PWS located more than a 0.5-mile away, the results do not confirm that the higher levels are caused by MassDOT SICP operations since other contributing factors can influence sodium levels in PWS as well. To assess whether the sodium data for PWS located inside and outside a 0.5-mile radius of a MassDOT roadway are statistically different in terms of the percentages of PWS that exceed certain sodium thresholds, a Kruskal-Wallis test was performed, which is non-parametric alternative to a one-way ANOVA statistical test (McDonald, J.H., 2014). The results of this test using a significance level of $\alpha = 0.05$ indicates that the null hypothesis cannot be rejected meaning there is not enough evidence to suggest that the concentrations between the data sets are significantly different.

Other factors including the use of treatment chemicals, proximity to brackish or ocean waters, groundwater flow velocity and direction, cumulative precipitation totals and the influence of other road salt users were not evaluated in this analysis. The collective influence of these other factors may in part explain the lack of significant difference. PWS that are within a 0.5-mile of a MassDOT road are also likely to be located in more urbanized areas given the greater roadway density needed to serve the higher population density. Urbanization also results in more commercial and retail development since commercial services are often preferentially located adjacent to major state roads. These businesses often have their own public wells. The sodium levels in these PWS are likely to be influenced by combination of road salt uses including that used on

municipal roads and parking lots. Whereas, PWS located more than a 0.5-mile from a MassDOT road are more likely to be located in rural, less developed areas with fewer road salt sources in the surrounding landscape and, therefore, will have lower sodium levels. The influence of road salt use on commercial parking lots versus that used on state roadways is difficult to differentiate without detailed hydrogeologic studies.

These results are generally consistent with the findings of a 2015 Worcester Polytechnic Institute (WPI) study entitled *A Framework for Assessing Impacts of Road Salt on Groundwater Supplies in Massachusetts*, which evaluated sodium concentrations in groundwater wells across Massachusetts (Gigliotti et al., 2015). The WPI study concluded that a majority of PWS utilizing groundwater had sodium levels above the recommended guidance level of 20 mg/L based on sodium data collected in the last 6 years and that sodium levels appear to be trending upward primarily in urbanized areas, which is discussed in Section 2.4.3 below and depicted in sodium concentrations graphs for municipal PWS included in **Appendix B**.

The highest reported maximum sodium concentration was 5,100 mg/L, which is associated with a non-community PWS that serves a golf course in the Town of Bolton and is more than a mile from the nearest MassDOT road. Apparently, based on information provided by MassDEP, the reported elevated sodium level is based on sampling data from the backwash of the onsite treatment system used to treat hardness and not from the water supply itself. For PWS that are located within a 0.5 mile of a MassDOT roadway, the highest maximum sodium concentration reported in the last five (5) years was 1,780 mg/L associated with the Boxboro Executive Center office building located off Route 111 in Boxboro. MassDOT has been in communication with the building owner and MassDEP to evaluate the situation. Although this particular PWS is approximately 300 feet from a MassDOT road and also near a MassDOT storage shed, this PWS also apparently uses salt to treat for hardness. Recent sodium data provided by MassDEP indicates that sodium levels in the raw water samples were considerably lower than levels measured in the finished water on numerous occasions and at times by as much as 50% or more. The higher sodium levels in the finished drinking water suggest that the treatment chemicals are having an effect. The treatment system backwash is also likely discharged onsite since there is no municipal sewer system, which may lead to increased levels in the local groundwater supplying the onsite well.

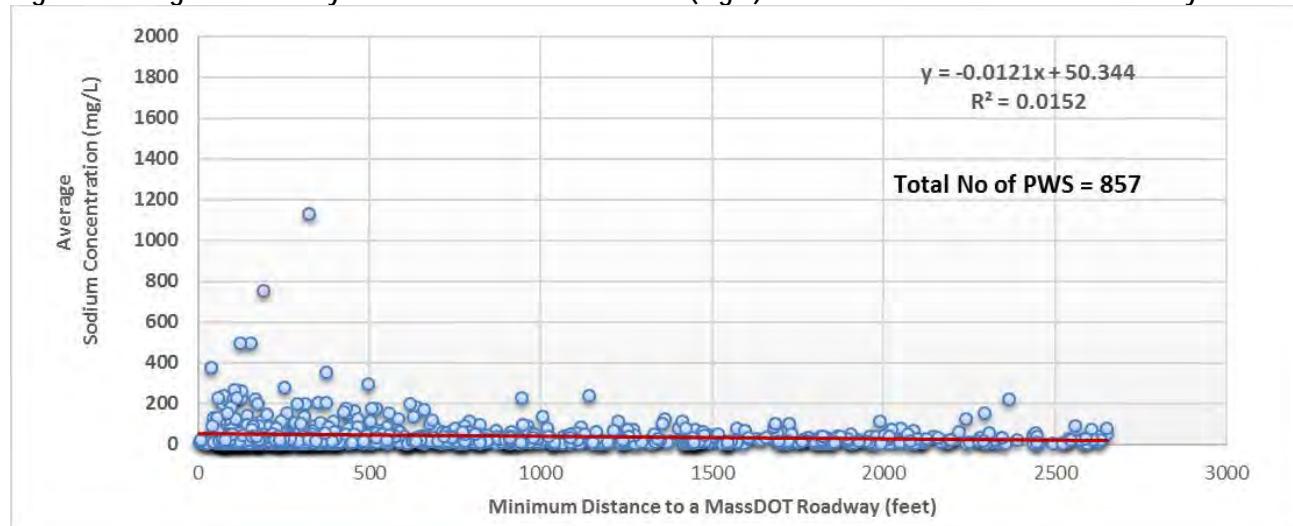
2.4.3 Sodium Concentrations vs. Distance to a MassDOT Road Regression Analysis

As shown in Figure 2.3, a regression analysis was done to evaluate the potential relationship or correlation between reported average sodium levels and the estimated distance to a MassDOT road for 857 individual PWS identified as being within a 0.5-mile of a MassDOT road. The average sodium concentration was based on reported data collected from 2012 to 2016. Although several PWS within 500 feet of a MassDOT road have relatively high sodium concentrations, the slope of the regression line is essentially flat indicating that the average sodium concentration changes only slightly as distance from a MassDOT road increases. The regression analysis produced a correlation coefficient (R^2 value) of 0.015, which suggests a minimal correlation between distance to a MassDOT road and the average sodium concentration. The R^2 value suggests that distance to a MassDOT roadway explains only about 1.5% of the variability in the reported average sodium concentrations for various PWS located within 0.5-mile of a MassDOT road. The highest average sodium level at just under 1,200 mg/l is associated with a PWS serving the Boxboro Executive Center, which, as discussed above, treats for hardness by adding sodium chloride which is likely to greatly influence sodium levels. Other PWS within a 0.5-mile of a road could be influenced by similar unrelated sources or additives as well.

In review of the Draft ESPR, MassDEP suggested that the regression analysis be expanded to include sodium data from PWS located beyond a 0.5-mile of a MassDOT road as well. However, using data from PWS located farther

away from a MassDOT road would seem to dilute the analysis or make it less rigorous or illuminating in terms of assessing the potential impact that MassDOT operations may have on sodium levels in PWS. Although not shown here, the regression analysis was redone using all PWS that had reported sodium data from 2012 to 2016 (See Response to Comments in Appendix A). The resulting correlation coefficient (R^2 value) was even lower at 0.013 compared to 0.015 when including PWS within 0.5-mile of a MassDOT road. Both R^2 values are very low and suggest minimal correlation between PWS sodium levels and distance to a MassDOT road.

Figure 2.3: Regression Analysis of Sodium Concentrations (mg/L) and Distance to a MassDOT Roadway



Notes: The average was based on multiple sources associated with each PWS collected between 2012 and 2016.

2.4.4 Sodium Concentration Trends in Municipal Water Supplies

An analysis of the sodium concentration trends was also conducted for municipal PWS that are located within a 0.5 mile of MassDOT's larger roadways. The purpose of this analysis was to identify if any discernable trends in sodium levels within some of the larger municipal PWS located near major roads, particularly in recent years. Only municipal PWS that had more than six (6) years of sodium data were evaluated. Given that MassDOT has decreased its average annual road salt usage in recent years by 24%, it would seem reasonable to expect that sodium levels would also decline if MassDOT's road salt usage was the primary source of the sodium inputs.

Table 2.4 presents a summary of average sodium concentrations calculated over 5-year intervals for various municipal PWS based on sodium data going back to 1993. The average concentrations are based on sampling results from multiple sources and sampling dates for each PWS within each 5-year interval. As mentioned earlier, most PWS are only tested once every three (3) years and do not have sodium data for every year.

Several municipal PWS listed in Table 2.4 show average sodium levels increasing over time going back to the 1990's. Several PWS show more distinct increases when comparing average concentrations from 2008 to 2012 and then 2013 to 2016. These include municipal PWS in Auburn, Billerica, Cambridge, East Chelmsford, Marlborough, Millbury, North Chelmsford, Weymouth and Wilmington. These increases occurred even though MassDOT has reduced its salt usage in recent years, which suggests that other sources, such as road salt use on impervious surfaces in developed areas may be contributing the rise in sodium levels. Long-term precipitation patterns can also cause sodium concentrations to fluctuate. Detailed hydrologic investigations and loading assessments would be needed to more definitively assess the relative contributions or influence of these potential sources have on sodium levels given various site-specific factors. Detailed time series graphs of sodium concentrations in various municipal PWS are provided in **Appendix B**.

Table 2.4: Average Sodium Concentrations in Selected Municipal Water Systems over 5-Year Intervals

Town	No. of Readings	Sodium Conc. (mg/L) Trends Based on Five Year Averages ¹				
		1993 – 1997 Average	1998 – 2002 Average	2003 – 2007 Average	2008 – 2012 Average	2013 – 2016 Average
Auburn	103	59.4	163.1	240.5	255.4	324.9
Billerica	35	n/a	n/a	61	94.2	357.1
Burlington	69	22.4	52.1	69.9	88.0	106.7
Cambridge ²	264	37.1	45.4	77.1	69.4	103.2
Chelmsford	128	31.6	38.3	52.0	56.6	65.3
Concord	74	12.0	21.8	28.1	60.1	96.0
Dedham	40	41.4	35.9	59.7	76.7	86.8
East Chelmsford	5	n/a	n/a	138	128	175.5
Franklin	89	22.7	114.5	80.8	56.6	89.1
Hamilton	29	n/a	n/a	44.6	74.7	55.5
Marlborough	14	n/a	n/a	103.1	116.6	160
Middleboro	87	28.3	24.3	30.9	47.4	76.0
Millbury	95	36.9	84.9	74.9	108.6	173.1
Natick	37	n/a	41.6	52.3	59.6	83.6
North Attleboro	47	21.5	n/a	84.4	29.5	n/a
North Chelmsford	424	90.3	122.6	149.1	129.3	140.3
Orange	6	n/a	n/a	96.7	100	101.3
Oxford	54	24.1	37.7	46.7	47.3	66
Reading	14	140.6	52.0	61.8	n/a	n/a
Rowley	6	n/a	n/a	74.3	100	114
Salisbury	44	33.0	52.6	56.8	85.7	106.9
Shrewsbury	44	n/a	n/a	81.0	36.7	77.3
Topsfield	19	n/a	n/a	625.6	28.9	n/a
Wakefield	13	n/a	n/a	78.0	70.3	82.2
Webster	67	n/a	n/a	20.2	50.34	86.5
Wellesley	151	40.3	48.4	60.6	66.1	77.3
Weymouth	41	96.4	n/a	145.7	84.1	114
Wilmington	121	58.4	67.0	69.5	88.2	128.8
Woburn	221	30.4	20.1	68.6	79.6	92.9

Notes: ¹Since each town did not report in the same year, the data was averaged over 5-year intervals;

²Sodium data for Cambridge Water District was supplied by the water supplier in November 2017 as the data was not included MassDEP database n/a = data not available

In other municipal PWS, sodium levels have remained relatively constant or have decreased in recent years such as in the towns of Chelmsford, Franklin, Hamilton and Topsfield. It is difficult to discern trends if there is limited data for the last 5 or 6 years, as is the case in several communities. MassDOT has been in communication with and working with public water suppliers in Auburn, Cambridge, Dedham-Westwood, Middleboro, Orange and Wilmington. In these locations, MassDOT has either established Reduced Salt Zones and/or recently implemented equipment upgrades and various efficiency measures to minimize salt usage. The effect of these measures in the Dedham-Westwood area were discussed previously in Section 2.3.3. Material spreaders used in these areas will be equipped GPS/AVL technology, which will allow more precise tracking of material usage within the contributing areas.

2.5 Evaluation of Chloride Levels in PWS

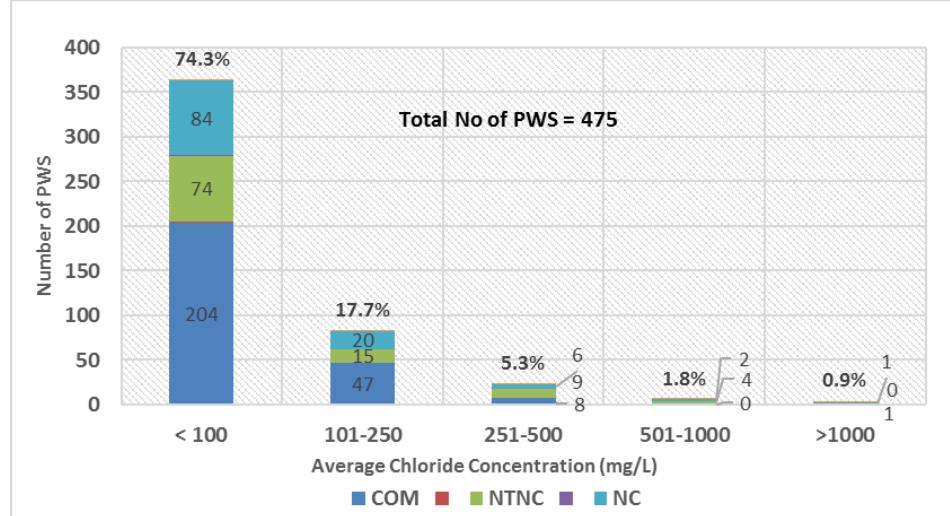
Chloride in drinking water is regulated as a secondary drinking water contaminant for aesthetic reasons to avoid issues with taste. MassDEP has set a secondary maximum contaminant level (SMCL) for chloride at 250 mg/L. Chloride levels above 250 mg/L may result in a salty taste, but are not considered to be a direct human health risk. Aside from the issues associated with taste, recent research suggests that the levels of various water quality constituents in source waters, including elevated chloride levels and the relative balance of various anions and ions can affect the corrosiveness of the water and possibly increase leaching of lead and other metals from pipes and plumbing fixtures into the water supply system (EPA, 2016).

A report by Nguyen et al., (2011) suggests that higher ratios of chloride to sulfate ions can increase galvanic corrosion with lead based solder used on copper pipes which can potentially release lead into drinking water. The report suggests that chloride-to-sulfate mass ratios (CSMR) above 0.7 can potentially increase corrosiveness at the lead solder/copper interface. The corrosiveness of the source water is also influenced by the presence and interactions with other water quality constituents such as pH, alkalinity or buffering capacity, dissolved inorganic carbon (DIC), total dissolved solids (TDS) and hardness. This research has raised awareness of the importance of monitoring drinking water for various parameters and how the use of chemicals for treatment purposes such as for hardness, disinfection or coagulation can affect water chemistry and the corrosive nature with metal surfaces in the water distribution system. Sodium or potassium chloride salts are often used to treat hardness through ion exchange to remove minerals. These systems typically generate waste brine solutions that are often backwashed into an onsite holding tank or septic system if no sanitary sewer is available. This brine backwash can introduce high chloride levels into the underlying groundwater depending on the backwash discharge location relative to the well location.

PWS are not required to test for chloride but it is recommended, especially where sodium levels are elevated. The MassDEP database had a total of 475 PWS that had reported chloride data from 1,158 different sources. An analysis of this data is summarized below and presented in Figure 2.4.

As shown in Figure 2.4, approximately 92% of the PWS with reported chloride data have an average chloride concentration below 250 mg/L. Of these, approximately 74% had an average chloride concentration below 100 mg/L while the other 18% had average chloride concentrations between 100 and 250 mg/L.

Figure 2.4: Summary of PWS with Reported Chloride Levels within Certain Concentration Ranges



Note: Only PWS that are located within 0.5 miles of MassDOT are included.

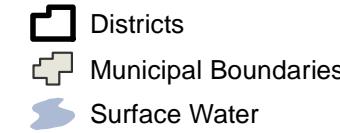
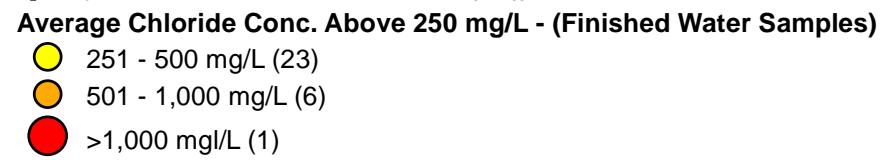
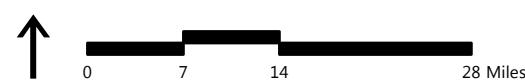
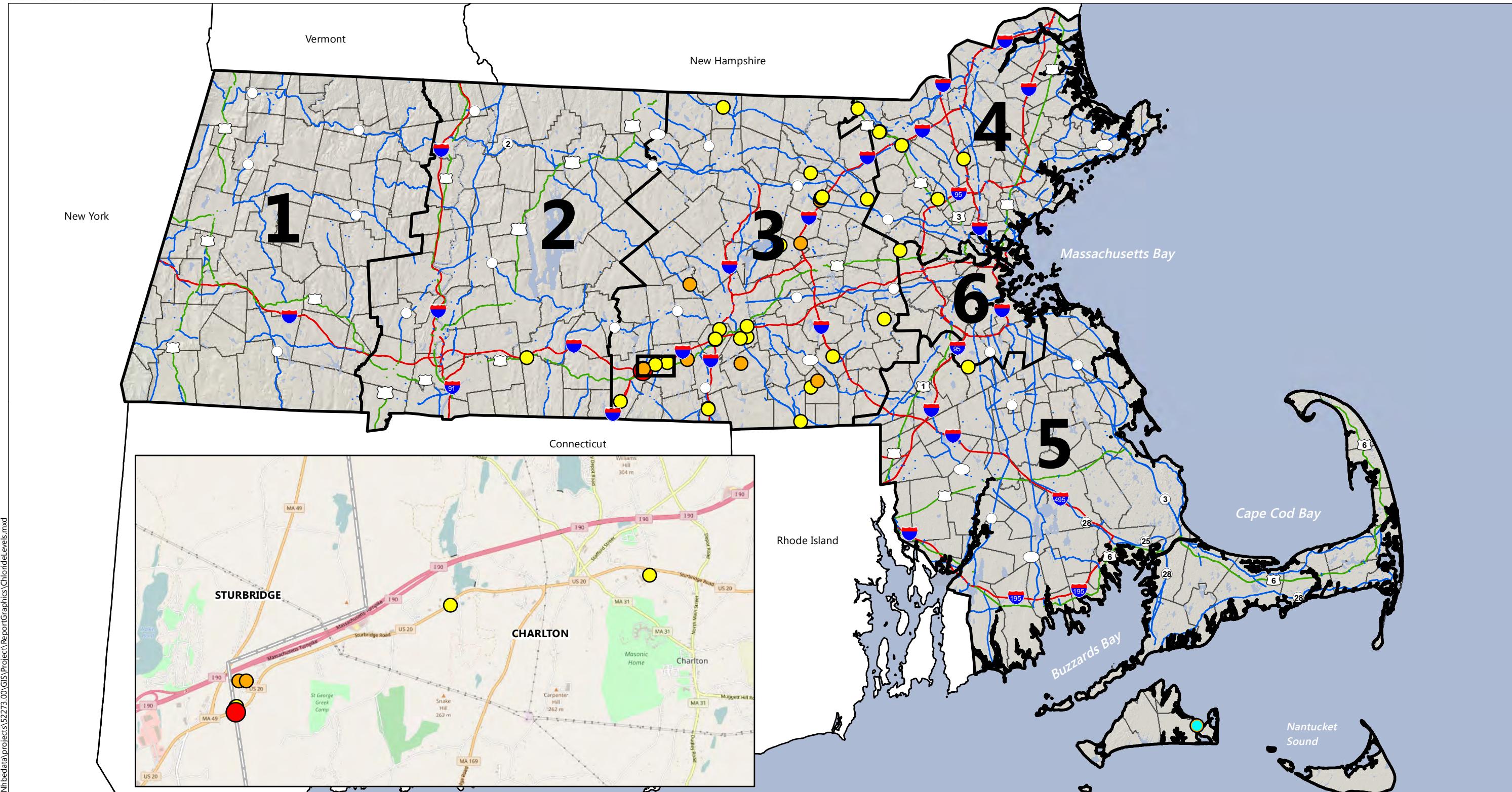
The remaining 8% of the PWS consist of thirty (30) PWS that have average chloride concentrations above 250 mg/L. Of these PWS, eight (8) are community wells, thirteen (13) are non-transient, non-community wells and the remaining nine (9) are non-community, transient wells. Six community wells have average chloride concentrations between 250 and 500 mg/L and two have average chloride levels between 501 and 1,000 mg/L. Table 2.5 lists the PWS that have average chloride concentrations above 250 mg/L in each PWS category. See Figure 2.5 that shows locations of PWS with chloride levels above 250 mg/L.

Table 2.5: Summary of PWS with Average Reported Chloride Concentrations Above 250 mg/L

PWS Category	PWS Name	Average Chloride Conc. (mg/L) ¹	No. of Sources	Town
Community	Brook Village Condominiums	466.0	2	Boxborough
	East Chelmsford District	410.0	3	E. Chelmsford
	Auburn Water District	365.0	5	Auburn
	Aquarion Water Company Millbury	320.0	3	Millbury
	Pine Hill Condominiums	310.3	1	Acton
	North Chelmsford Water District	268.0	8	N. Chelmsford
	Campion Residence and Renewal Ctr	264.5	1	Weston
	Wilmington Water Department	257.2	4	Wilmington
	Country Courtyard	633.0	1	Templeton
Non-Community, Non-Transient	60 & 70 Codman Hill Rd	526.0	1	Boxborough
	Henry P Clough School	526.0	1	Mendon
	Heritage Professional Bldg	526.7	1	Berlin
	Piconics	488.0	1	Tyngsboro
	Winstanley Enterprises	478.1	1	W. Concord
	The Appleworks	449.0	1	Harvard
	Sutton Public Schools	444.0	2	Sutton
	159 Swanson Rd Setra Systems Inc	279.3	1	Boxborough
	Pilgrim Church	264.7	1	Leominster
	155 Swanson Rd. Synquor	261.0	1	Boxborough
	Pilot Travel Center	254.0	1	Sturbridge
	Ashby Elementary School	250.8	1	Ashby
	Assembly of God Southern N.E. Dist.	1400.0	1	Charlton
	Chappaquiddick Beach Club, Inc.	1000.0	1	Edgartown
Non-Community, Transient	Dads Restaurant	574.0	1	Charlton
	Flat Penny Restaurant	416.0	1	Berlin
	Howlett Lumber/Flea Market	418.0	1	Charlton
	Imperial Ballroom	366.0	1	Mendon
	Sims Health and Racquet Club	340.0	1	Charlton
	McDonald's Restaurant	327.5	1	Uxbridge
	CJs Restaurant	255.0	1	Palmer

Note: ¹ The average concentration represents an average across multiple sources and/or sampling years based on data contained in MassDEP PWS drinking water database as of August 2016.

Overall, the reported chloride data contained in the MassDEP database indicates that approximately 8% of the PWS sources have average chloride levels above the recommended SMCL level of 250 mg/L. Elevated chloride levels above the SMCL appear to be limited to a few central Massachusetts locations and does not appear to be a widespread issue throughout the state. However, PWS with average chloride levels above 500 mg/L may warrant more detailed investigations to try to identify the source(s) of chloride and whether the elevated levels are contributed to increased corrosiveness. PWS that are adding salt to treat for hardness may represent a significant source of the chloride levels. Testing for other parameters such as copper or lead that are typical indicators of corrosion should also be considered.



MassDOT

Figure 2-5
Public Water Supplies with Average Chloride Levels Above 250 mg/L

June 23, 2017

Source: MassGIS, MassDOT, VHB

2.6 Research Related to Environmental Resources

The following provides an update on recent literature research about the potential environmental impacts from deicing chemical usage as well as update on the sensitive environmental resource areas located within the Commonwealth. The sensitive environmental areas include Areas of Critical Environmental Concern (ACEC) and Priority Habitats and Natural Communities, as designated by the Massachusetts Natural Heritage and Endangered Species Program (MNHESP), a division of the Massachusetts Division of Fisheries and Wildlife. This section provides a general update regarding Kampoosa Bog located along the Mass Turnpike in Stockbridge and Lee, which was identified as a particular area of concern in recent agency comments.

2.6.1 Statewide Designated Environmentally Sensitive Areas

ACEC's are designated areas that are protected and regulated under state regulations 301 CMR 12.00 and are considered to have a unique set of natural and human resource values worthy of protection. Designating an area as an ACEC requires a five-step process including a formal nomination, a review by the EEA Secretary, public hearings, a decision by the Secretary, and publication of notice in the Environmental Monitor. The designation process determines whether the nominated area is of regional, state, or national importance and/or contains significant ecological systems with critical interrelationships among several components.

As shown in Table 2.6, there are twenty-nine (29) designated ACEC's within the State of Massachusetts encompassing a total area of approximately 268,000 acres. The Squannassit ACEC is the largest ACEC consisting of approximately 37,420 acres in size and is in the central and northern sections of MassDOT's District 3 along the Nashua River from Harvard and Lancaster north to New Hampshire. The Squannassit ACEC is adjacent to two other large ACEC's, the Central Nashua River Valley ACEC and the Petapawag ACEC, and shares abundant physical, biological, cultural, and historical resources associated with the Nashua River Corridor. The Pocasset River ACEC, located in District 5, is the states' smallest ACEC and is comprised of 160 acres of river and estuarine habitat located on the eastern shore of Buzzards Bay and in the Town of Bourne. District 5 has more designated ACEC's than any other district due to the unique habitat and hydro-geologic conditions of Cape Cod and the southeastern coastal region of the state.

Priority Habitats, as identified by the Natural Heritage & Endangered Species Program (NHESP), represent another significant ecological area regulated within the state of Massachusetts. Priority Habitats generally represent known habitat areas for state-listed rare species, both plants and animals, as codified under Massachusetts Endangered Species Act (MESA). Any proposed habitat alteration within a Priority Habitat may adversely impact and potentially result in a "take" of a state-listed species, and are subject to regulatory review to ensure compliance with NHESP for MESA. Priority Habitat maps are used for determining whether a proposed project must be reviewed. There are also "Estimated Habitat Areas of Rare Wildlife," which are a subset of Priority Habitat areas and represent the geographical extent of the habitat of state-listed rare wetland wildlife and are codified under the Wetlands Protection Act. The NHESP also identifies a third key type of ecological area known as "Priority Natural Communities". These areas are identified as having natural communities that are considered uncommon and/or exemplary within the state.

The NHESP GIS mapping data (downloaded September 2016) indicates that approximately 1,579 areas are designated as NHESP Priority Habitat for Rare Species within the Commonwealth and 1,323 distinct areas are designated as NHESP Natural Communities.

Table 2.6: Designated Environmentally Sensitive Areas within each District

MassDOT District	No. of ACECs	NHESP Priority Habitats	NHESP Natural Communities
1	5	293	176
2	0	244	191
3	5	288	106
4	2	166	40
5	13	555	803
6	4	33	7
Total:	29	1,579	1,323

Table 2.7 lists various ACECs within each District that are traversed or are directly adjacent to a MassDOT roadway. Each District, except District 2, has several designated ACECs that are bordered or traversed by a MassDOT highway. Districts 1 and 3 have five designated ACECs, while District 4 has only two ACECs and District 5 has thirteen ACECs that are adjacent to or traversed by a MassDOT highway.

Of the five ACECs located in District 1, Kampoosa Bog may be the most notorious since it has been the subject of several studies investigating the potential effects of road salt applications on vegetation. As discussed in the following section, both I-90 (Massachusetts Turnpike) and Route 7 directly border the edges of the Bog. In District 3, Cedar Swamp ACEC and the Miscoe, Warren, and Whitehall Watershed ACECs are very close to several major interstate roadways including I-495 and I-90.

In the northern portion of District 3, the Central Nashua River Valley ACEC is bordered by a segment of I-190 along its westernmost boundary. This ACEC contains approximately 20-miles of the North Nashua and Nashua Rivers. The Petapawag and Squannassit ACECs also have several state highways that traverse through them, but these ACECs are relatively large and are located within a less densely developed, rural portion of the state.

District 4 has two ACEC areas, including the Rumney Marsh and the Great Marsh ACECs that are bisected by MassDOT highways. Both these ACECs are in the coastal region of the state and in highly urbanized areas. Rumney Marsh is located within the towns of Lynn, Revere and Saugus, and extends south into Boston and Winthrop and into District 6. This ACEC is bordered by portions of Routes 1A, 107, 145, and 60. Given that both ACEC's are tidally influenced, they are less likely to be affected by MassDOT SICP activities.

District 5 and portions of District 6 have several ACECs (Fowl Meadow and Ponkapoag Bog and Neponset River Estuary) that are adjacent to segments of I-95 and/or I-93. I-495 and several other secondary state routes are located within the watersheds of the Canoe River Aquifer, the Hockomock Swamp and the Three Mile River ACECs. These areas are within a region of the state with some of the highest densities of impervious area.

Table 2.7: ACECs Located Adjacent to or Traversed by a MassDOT Roadway in each District

District	ACEC Name	MassDOT Roadways
District 1	Schenob Brook Drainage Basin Hinsdale Flats Watershed Karner Brook Watershed Kampoosa Bog Drainage Basin Upper Housatonic River	Routes 7, 7A, and 41 Routes 8 and 143 Routes 7, 23, and 41 I-90, Route 7 Route 7
District 2	none	--
District 3	Cedar Swamp Central Nashua River Valley Miscoe, Warren, and Whitehall Watersheds Petapawag Squannassit	I-495, I-90, Route 140, 135 I-190, Routes 2, 70, 110, and 117 I-90, Route 140 Routes 40, 111, 113, and 119/225 Routes 2, 2A, 13, 31, 111, 113, 119, 225
District 4	Rumney Marshes Golden Hills	Routes 1A, 60, 107 None
District 5	Great Marsh Three Mile River Watershed Canoe River Aquifer Fowl Meadow and Ponkapoag Bog Hockomock Swamp Weir River Estuary Pleasant Bay Pocasset River Sandy Neck Barrier Beach System Waquoit Bay Herring River Watershed Ellisville Harbor Bourne Back River	Routes 1, 1A, 133 I-495, Routes 44, 123, 138, and 140 I-495, Routes 24, 106, 123, and 138 I-95, Route 1 I-495, Routes 24, 104, 106, 123, 138 Route 228 Route 28 None Route 6A Route 28 Routes 3 and 6 Route 3A Route 28
District 6	Weymouth Back River Wellfleet Harbor Inner Cape Cod Bay Rumney Marshes Neponset River Estuary	3A Route 6 Route 6 Routes 1A, 145 I-93, Routes 3A, 203

The Canoe River Aquifer is designated a Sole Source Aquifer by the EPA based on the assumption that the watershed area supplies 50% of the drinking water consumed within the area overlying the aquifer. The aquifer currently provides drinking water for approximately 66,000 people within four towns. As stated in the EPA's 1993 Notice of Designation (58 FR 28402), the Canoe River Aquifer is considered highly vulnerable to elevated salt concentrations due to its geological characteristics and nearby land use activities. The Aquifer is a stratified drift aquifer consisting of shallow sand and gravel deposits. Due to the shallow nature of this aquifer and its presumed vulnerability to potential contaminants and the fact that it is the principal source of drinking water for the residents of four towns, this could be the most critical ACEC in District 5.

2.6.2 Kampoosa Bog, Stockbridge and Lee, MA

The Kampoosa Bog, located adjacent to I-90 (Massachusetts Turnpike) in the towns of Stockbridge and Lee, has been the subject of concern and research relative to the potential road salt effects on vegetation.

Approximately 2 miles of Mass Turnpike in District 1 directly borders the northern boundary of Kampoosa Bog as well as a portion of Route 7 also maintained by MassDOT (Refer to Figure 2.6).

The Bog is a large wetland complex, approximately 1,350 acres in size, comprised of red maple swamp areas and a calcareous (calcium-rich) basin fen surrounded by an open water area. Previous research has detailed vegetation and chemistry changes within the Bog. The Bog was designated as an ACEC in 1995 after being nominated by the Stockbridge Land Trust and completion of an Ecological Designation Report prepared by the former Massachusetts Department of Environmental Management.

Dr. Julie Richburg of the UMass Department of Natural Resources Conservation was first to document the presence and growth of Phragmites (*Phragmites australis*) along the Turnpike right-of-way. Phragmites is a salt tolerant species that is highly aggressive and opportunistic plant and quickly colonizes recently disturbed areas if there is an available seed mix nearby. The results of this study were published in a report entitled, "Effects of Road Salt and *Phragmites australis*: Invasion on the Vegetation of a Western Massachusetts Calcareous Lake-Basin Fen" (Richburg et al., 2001). Once established, Phragmites can spread, quickly out-compete, and overcome native species and can adversely affect habitat conditions and plant diversity in the existing plant community.

As part of this study, water quality samples were collected from numerous wells throughout the northeastern portion of the Kampoosa Bog where Phragmites was most abundant. The data revealed that the highest sodium and chloride concentrations were in the first 300 meters (900 feet) from the roadway. Sodium concentrations ranged from 200-390 mg/L, and chloride concentrations ranged from 210-275 mg/L. Average sodium and chloride concentrations approximately 650 meters (~2,000 feet) from I-90 dropped to approximately 80 mg/L and 60 mg/L, respectively. The sodium and chloride concentrations decreased even further to approximately 15 mg/L at approximately 2,500 feet (~0.5 miles) from the roadway.

The study authors also noted that pipeline construction work along the Turnpike right-of-way in 1991 may have contributed to the initial establishment of Phragmites in this area. Review of aerial photographs from 1952, 1972, 1985, and 1991 indicated that Phragmites was not apparent prior to the pipeline activity. Phragmites first became evident in 1992 along the northern edges of bog adjacent to the Turnpike right-of-way. Once established, researchers suggest that the elevated sodium and chloride levels potentially created more favorable conditions for Phragmites to outcompete other vegetation species in the emergent marsh.

Another study completed in 2008 by Dr. Amy Rhodes of Smith College evaluated the relative influence of surface runoff and shallow and deep groundwater flow on water chemistry within the wetland. The study found that water chemistry was influenced by surface and shallow ground water flow from the Turnpike area. The study also found that large rain and snowmelt events caused significant amounts of salt-related cations and anions to be exported from the fen during non-winter months. Data showed that more than half of the estimated annually applied sodium and chloride applied to the Turnpike was flushed out of the watershed during March-May (Rhodes et al., 2008).

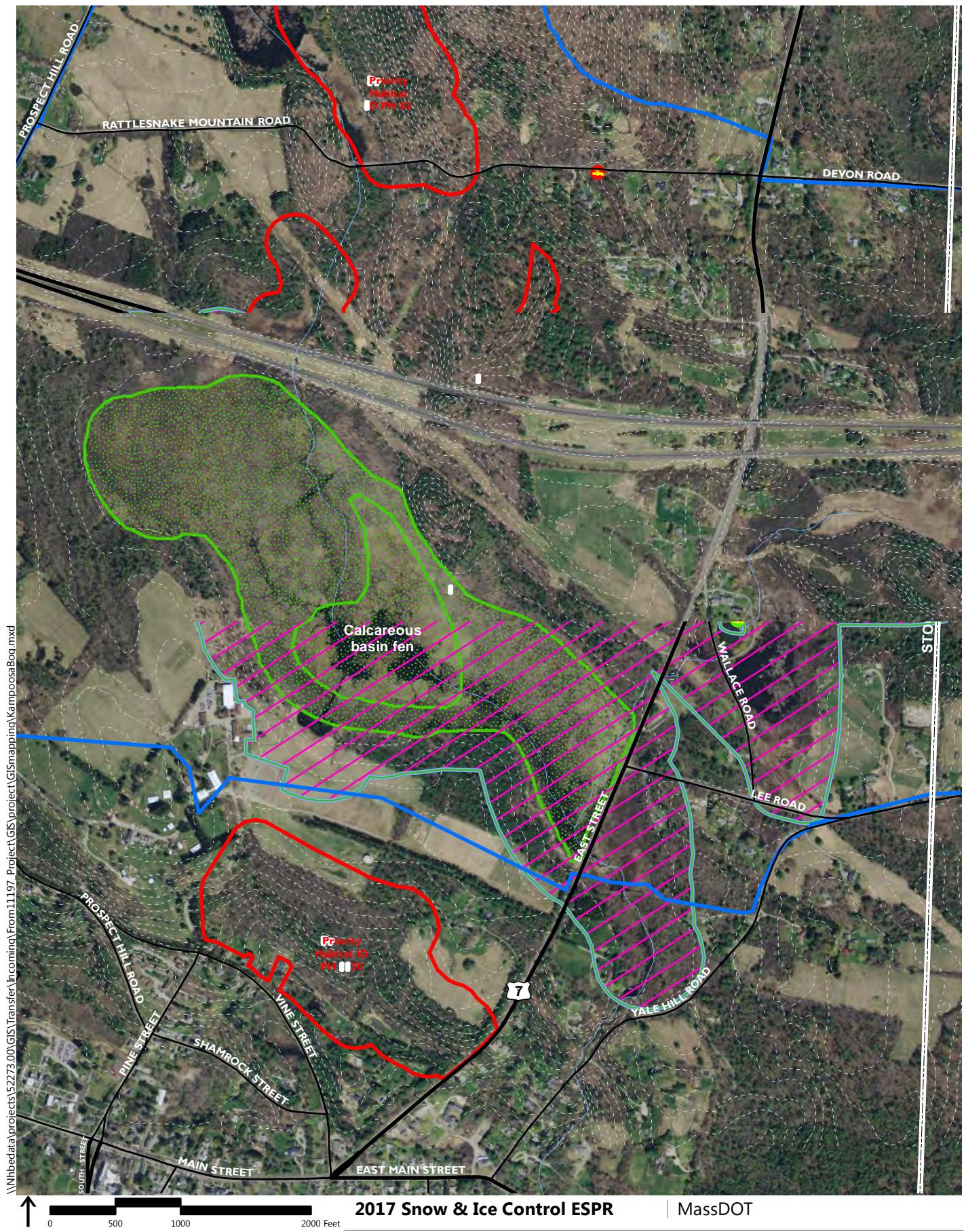


Figure 2-6
Kampoosa Bog
Stockbridge, MA

Source: MassGIS, MassDOT, VHB

In recent years, following the merger with Mass Turnpike, MassDOT initiated several measures to minimize the amount of road salt used on roadways adjacent to Kampoosa Bog. First and foremost, MassDOT initiated a pilot study to develop a system to electronically track road salt usage using the computer controllers along the roadway sections adjacent to the Kampoosa Bog. It took several years to work out the electronic hardware and software glitches, but during the last winter season (2015-16), district personnel reported that using technology resulted in road salt usage along these sections of road to be much more consistent and generally lower than that used in other regions of the state. District personnel plan to build on the early success and improve the tracking and reporting system. This information was recently shared with the NHESP, who recognized and supports further uses of this innovation as described in their May 20, 2016 comment letter following review of the Draft Work Plan (DWP) for the 2017 MassDOT SICP.

MassDOT is currently contributing funds to support a natural community/vegetation mapping study to be conducted by NHESP personnel. This study will seek to map the extent of the sedge fen habitat area as well as the distribution and limits of cattail plants and other invasive species.

2.6.3 Potential Impacts to Aquatic Resources

Recent studies have documented increasing chloride concentrations in rivers and streams throughout the northeast and other snow belt states. The U.S. Geological Survey reported that the mean annual chloride concentrations in the Merrimack River have increased from 2.9 mg/L in the early 1900s to 24.9 mg/L as measured in 1995 (Robinson et al., 2003). Kaushal et al., 2005 reported observed chloride concentrations in streams in urban areas of Maryland, New York and New Hampshire being 100 times greater than that in unimpacted forest streams during summer months. In some urban streams, chloride concentrations were close to 25% of the concentrations found in seawater. Mullaney et al. (2009) reported that chloride increases are largely attributable to urbanization based on a comprehensive review of water quality data collected from 100 different streams throughout northeastern United States. The median chloride concentration was 3.5 mg/L in forested basins, 21 mg/L for watersheds largely composed of agricultural areas, and 81 mg/L for more urbanized watersheds. The study authors estimated that the mean annual chloride loads were 6.4, 15.4 and 88 tons/mi² for forested, agricultural and urban watersheds, respectively.

In 1988, EPA published recommended Ambient Water Quality Criteria for chloride for the protection of aquatic life based on limited toxicity studies conducted and reported in the literature prior to 1985. The recommended water quality criterion for chronic exposure was established at 230 mg/L based on a four-day average concentration not to be exceeded more than once in a three-year period. The recommended acute water quality criterion was established at 860 mg/L based on a one-hour average concentration not to be exceeded more than once in a 3-year period. Given that these criteria are based on either four-day or one-hour average concentrations, determining if existing chloride levels exceed these thresholds will require continuous measurements at frequent intervals during peak periods to develop representative one-hour and four-day average chloride concentrations. Secondly, the sampling should be done over a sufficient long-term period to assess the return frequency of any peak concentrations observed and whether these peak concentrations would occur more than once in the specified 3-year return frequency.

Table 2.7 lists six (6) water bodies identified by MassDEP as being chloride-impaired according to the Massachusetts 2014 Integrated List of Waters (Massachusetts Division of Watershed Management, 2015). Four of these streams are located along the I-93 corridor in the Towns of Andover, Wilmington, and Tewksbury including an unnamed tributary to Martin's Brook in Wilmington, an unnamed tributary to the Shawsheen River

near Dascomb Road in Tewksbury and Pinnacle Brook and Fish Brook in Andover. These impairments were based on data collected by the EPA in 2009 using continuous data loggers to record specific conductance measurements as well as grab samples for chloride. EPA's data indicated that the acute or chronic standards of 860 and 230 mg/L were exceeded based on estimated four-day or one-hour average chloride concentrations, respectively, using an empirical relationship between observed chloride concentrations and specific conductance measurements (EPA, 2010).

Watershed maps showing the general locations and surrounding land uses associated with these impaired water bodies are included in **Appendix C**. As shown on these maps, most of these impaired segments originate in residential and commercial land use areas located upstream of the major MassDOT roadways indicating that other road salt users or sources may be contributing to these impairments. In fact, for two of these streams, the West River and Sawmill Brook, there are no major roadways in the subwatershed areas draining to the designated impaired sections of these water bodies.

Table 2.7: Massachusetts Water Bodies Listed as Chloride Impaired Based on 2014 Integrated 305(b)/303(d) List

Water Body	Town	Segment ID	Length	Segment Description
West River	Upton/Uxbridge	MA51-12	9.3 mi	From the Upton WWTF Discharge to confluence with Blackstone River in Uxbridge.
Sawmill Brook	Newton	MA72-23	2.4 mi	Headwaters beginning in Newton to confluence with Charles River in Boston.
Unnamed Tributary to Martins Brook	Wilmington	MA92-26	1.3 mi	Beginning west (upstream) of I-93 near Route 125/93 interchange to confluence with Martins Brook.
Unnamed Tributary to Meadow Brook (aka Pinnacle Brook)	Andover/Tewksbury	MA83-15	2.1 mi	Beginning east (upstream) of I-93 in residential area of Andover flowing west to Meadow Brook in Tewksbury
Unnamed Tributary to the Shawsheen River	Andover/Tewksbury	MA83-20	0.9 mi	Small intermittent tributary originating near Dascomb Road draining south to Shawsheen River.
Fish Brook	Andover	MA84A-40	4.1 mi	Begins in headwater area east of Greenwood Rd. (upstream of I-93) flowing west beneath I-93 to Merrimack River north of I-495.

Note: Massachusetts Division of Watershed Management, 2015.

In developing Total Maximum Daily Load (TMDL) chloride load allocations for four chloride impaired streams in southern New Hampshire, approximately two-thirds of the existing chloride load to two of these streams was estimated to be linked to road salt used on municipal roadways and commercial parking lots (NHDES, 2008). The studies concluded to achieve meaningful sodium and chloride reductions in these affected water bodies, all road salt users would be required to implement efficiency measures to reduce their average annual usage by approximately 25 percent. As a result, New Hampshire Department of Transportation adopted anti-icing practices and equipment upgrades similar to those used by MassDOT in the last five or six years.

To assist the private contractor/commercial property sector, the NH Legislature passed legislation (RSA 508:22) in 2013, which granted limited liability protection to property owners for "damages arising from insufficiencies or hazards caused by snow and ice" if they hired a Certified Green SnowPro™ contractor to manage their

parking lots and roadways. To obtain certification, participants must attend a one-day training workshop, pass an exam and participate in a two-hour recertification program every two years. To maintain certification, contractors must report their annual salt usage through an online reporting system. More information on the NH Green SnowPro™ Program can be found at: <http://des.nh.gov/organization/divisions/water/wmb/was/salt-reduction-initiative/salt-applicator-certification.htm>,

A similar certification/training/reporting program would likely be needed in Massachusetts for the municipal and private contractor sectors to improve application and storage practices in watersheds of impaired streams. To establish a similar type of Certification Program in Massachusetts, stakeholders will need to be engaged early and appropriate legislation, regulations and perhaps funding would be required to accomplish this effort.

During field investigations in the I-93 Tewksbury-Andover area, MassDOT discovered an uncovered salt pile in a commercial parking lot located next to a catch basin that outlets directly to a tributary to the Shawsheen River. This salt pile would likely be a major contributor to the elevated chloride concentrations in this stream.

As mentioned above, NHDOT had determined that it could meet its recommended load allocation for existing conditions. However, to accommodate the proposed roadway improvements, NHDOT would be required to reduce its current annual road salt use by more than 70% in one small watershed. To meet this requirement, NHDOT would need to rely totally on non-chloride deicers, which would have substantial cost implications.

Cost information provided by Cyrotech Deicing Technology, Inc, a manufacturer of non-chloride deicers, indicated that the cost of CMA was approximately \$1,500 ton compared to approximately \$60 per ton for regular road salt. This would result in a 25-fold increase in material costs if CMA was used instead of sodium chloride. The average annual per lane mile cost would be \$22,500 compared to \$900 per lane-mile using regular road salt (\$60 / ton) assuming an average annual application rate of 15 tons per lane-mile. The cost differential to use CMA in place of road salt would result in a 10-fold increase in MassDOT's average annual material cost from approximately \$35 million to around \$360 million to maintain its approximately 16,000 lane-miles of roadway. This assumes that amount of CMA needed would be similar that used as road salt.

In the 1990's, MassDOT experimented with the use of CMA on a segment of Route 25 in southeastern Massachusetts. District personnel found that CMA did not perform as well as regular road salt in terms of melting snow and preventing ice formation. Thus, more CMA material had to be applied or needed to be augmented with regular road salt, which would only add to the estimated cost differential discussed above.

As discussed herein, MassDOT has made great progress in utilizing various measures to reduce its annual road salt usage by approximately 25% compared to what it used to use and intends to continue making progress in this area. Given the results of the published chloride TMDL studies discussed above, similar efforts would be required to address the contributions from all sources (i.e., parking lots and municipal roads) to achieve substantial reductions that would meet the water quality standards in chloride impaired water bodies.

2.6.4 Effects of Deicing Chemicals on Roadside Vegetation

Deicing chemicals used by MassDOT include sodium chloride, calcium chloride, and magnesium chloride in various forms during various weather conditions. Sodium and chloride are the two main ions that can negatively affect roadside vegetation. Roadside plants are potentially exposed to road salt inputs through two different avenues: 1) Root absorption, i.e. the uptake of salt contained in soil and soil water, and 2) Salt spray

on branches and foliage due to tire splash and wind. In the winter months, salt can build up on branches and twigs of deciduous trees and invade living tissue through existing leaf scars. Although salt spray is generally considered less damaging than root adsorption and usually does not result in outright death, it has been known to stunt bud development, flowering and foliar growth.

Root adsorption and salt spray can result in plant tissue damage due to a potential disruption in the ion exchange and an imbalance in the osmotic pressure across cell membranes. The excess sodium and chloride ions end up desiccating cells, leaving plant tissues in a vulnerable or weakened state (Berkheimer and Hanson, 2006). This osmotic imbalance can also occur in the root zone making it difficult for plants to draw water from the soil leading to additional drought-related stress. The typical symptoms of these effects generally manifest as browning of foliage, premature defoliation, diminished flowering and shoot growth and sometimes mortality, under severe conditions. Bryson and Barker 2002 reported that most plant damage is confined within ten meters (~30 feet) of the road and minimal effects were generally observed beyond 30 meters (~100 feet) based upon observations and plant tissue analysis conducted along roadways in Massachusetts.

The Colorado Department of Transportation and the University of Colorado have conducted further studies focused specifically on magnesium chloride. Studies concluded that magnesium chloride may be less detrimental than sand and other road salts such as sodium chloride. The study focused on current application rates and concluded that the effects of magnesium chloride are not likely to extend beyond 60 feet from the roadway. A study by the California Department of Transportation found that magnesium chloride is less likely to affect roadside vegetation because it is applied as a liquid and at a lower concentration level as compared to straight sodium chloride when applied in solid form (AASHTO, 2009).

Vegetation that are most sensitive to deicing chemical impacts include conifers and younger plants. Salt tolerant trees and shrubs include species such as shagbark hickory (*Carya ovata*), ginkgo (*Ginkgo biloba*), black walnut (*Juglans nigra*), quaking aspen (*Populus tremuloides*), white oak (*Quercus alba*), butterfly bush (*Buddleja davidii*) and serviceberry (*Amelanchier canadensis*) (Jull, 2009). Several invasive species, such as burningbush (*Euonymus alatus*) and Japanese barberry (*Berberis thunbergii*) are salt tolerant and can readily take advantage of stressed native plant species. Magnesium and calcium have little to no effects to vegetation, since most plants are capable of processing high amounts of these ions (Casey et al., 2014).

Excess sodium in roadside soils can also contribute to increased vehicle collisions with wildlife because road salt along roadways attracts wildlife when they become salt deficient due to a lack of available food sources. When this occurs, the frequency of road kills generally increases. Many species are likely to compensate for their salt deficiency by eating/ drinking salty snow along roadways which can lead to elevated salt content in blood and tissues (AASHTO, 2009). Since sodium is the main attractant, magnesium chloride and calcium chloride pose much less of an effect on wildlife, but still can be toxic in smaller animals if ingested.

2.6.5 Effects of Road Salt Usage on Cranberry Bog Production

Following hay production, cranberry production ranks second among the major crops produced in the state. Nationally, Massachusetts produced approximately 30% of the cranberries grown in the country in 2011. In Massachusetts, the revenue generated by cranberry production was estimated to be just under \$104 million in 2011 and has been as high as \$138 million in 2008. Cranberries are grown on approximately 13,000 acres of land primarily located in southeastern Massachusetts (NASS, 2012). Cranberry bogs by their very nature can be

susceptible to the effects of road salt use on roadways because they rely on surface water drainage to support the production of cranberries. As roadways are extended or widened in areas of the southeast corner of the state such as when Route 25 was constructed in Wareham, consideration must be given as to how road runoff will be directed and whether it has the potential to enter nearby cranberry bogs.

In 2005, researchers at the UMASS Cranberry Research Station located in the Town of Wareham evaluated the effects of long term exposure of elevated levels of sodium and chloride in the irrigation water had on cranberry growth and production. Based on greenhouse studies and a soil free environment, the study results indicated that minor adverse effects of plant growth became visible when plants were exposed to chloride concentrations of 100 mg/L in irrigation water. At 250 mg/L, symptoms increased and flowering was suppressed. Cranberry growth was visibly suppressed at 500 mg/L Cl, and at higher concentrations plants exhibited severe leaf drop and eventual death.

In soil sorption/desorption studies, chloride concentrations that were greater than 250 mg/L resulted in significant and only partially reversible, changes to cranberry soil chemistry. At 250 mg/L, recovery occurred after desorption but these research results suggest that a cranberry water supply with chloride concentrations a 250 mg/L or greater would be cause for concern and indicate the potential need for remedial action. Symptoms, soil chemistry changes, and possible impedance of growth stimulation at 100-125 mg/L indicate that a cranberry water supply containing 100 mg/L or greater of chloride for extended periods might also be cause for concern. Taking these results into account, setting the level of concern for chloride in cranberry irrigation water at 100 mg/L appears warranted. This is well below the 250 mg/L that was linked to negative effects in greenhouse experiments and the 500 mg/L that negatively affected growth in soil-free culture (DeMoranville et al., 2005).

2.6.6 Maple Sugaring

The Massachusetts Department of Agriculture reports that there are approximately 300 maple syrup producers in Massachusetts, mostly located in the western half of the state. These producers typically generate 40,000 to 60,000 gallons of maple syrup each year valued at over \$3 million dollars (NASS, 2012). It is estimated that some 60,000 tourists spend over \$1.9 million a year during the maple sugaring season for maple related products and for meals and lodging accommodations. Several studies have reported that road salt can cause decreases in tree vitality, tree growth and increased salinity in maple syrup in roadside trees (Carroll et al., 1983, Dyer and Mader 1986, Herrick 1988). In general, elevated salt concentrations in soils can lead to decreased water uptake which causes tree stress similar to that observed during drought conditions. In researching this topic, there appeared to be few, if any, more recent studies on this topic and limited data on the potential direct impact that road salt may have on maple syrup production.

2.6.7 Environmental Impacts Associated Sand Use

Historically, sand was primarily used for traction benefits. It provides minimal deicing benefits to prevent ice formation on roadways. As traffic volumes and vehicle speeds increased, the traction benefits became even more marginalized. The applied sand particles are either quickly pulverized by passing vehicles or blown off the road if applied on dry pavement. One study showed that as much as 30% of dry sand is lost upon application, and as few as 8 to 12 cars can displace it from a dry roadway surface. Not only does it provide limited and temporary traction benefits, the additional post-season cleanup costs after application can be substantial. Oregon DOT found that as much as 50 to 90% of sand applied was left behind. Much sand accumulates on

roadside edges as well as within catch basins and drainage pipes, which results in flow restrictions and blockages in the stormwater drain system. To avoid blockages, sand left in ditches and on bridge decks will require cleanup via mechanical removal or water jetting (AASHTO, 2009).

Smith and Granato (2010) reported that the average sediment and phosphorus concentrations in highway runoff from principal roadways were found to be 3 to 10 times higher in winter months compared to that in non-winter months. The increases were largely attributed to the use of winter sand on roadways. In the Charles River watershed, where a phosphorus TMDL has been established, as well as other nutrient sensitive watersheds, the use of winter sand can represent a major source of phosphorus and have significant environmental impacts.

A study conducted by Langen et al., (2006) reported that sand used in winter road maintenance can have a negative impact to roadside vegetation since sand accumulation can decrease the soil's ability to retain water, since sand is more porous than silt or clay. Additionally, since sand retains little water, the nutrients contained in water are drained from the soil and therefore are not readily available to the roots of plants. Additionally, since the accumulation of sand displaces the amount of organic matter in the soil, this causes the cation exchange capacity of the soil to lower, which also inhibits nutrient availability to plants.

The application of sand has also been found to cause adverse human health effects in the form of respiratory problems associated with dust particles contributing to poor air quality. Several studies have found that residual dust generated from winter sand can contribute to air pollution. Based on ambient air particulate monitoring conducted in three cities including Albany, NY, Denver, CO and Reno, NV following the application of road sand, fugitive sand dust accounted for approximately 44% of the small particulates (<10 microns-PM 10) and road salt was attributed to 17%. Coarse road sand is transformed into finer particulates through grinding from vehicle tires. In Denver, more than 59% of the average ambient PM 10 levels, and a peak of 89%, were attributed to road sand. Similar findings were reported in Reno, NV, where re-suspended road sand was found to contribute 57% to the PM 10 levels on average, while motor vehicles contributed 22% and highway salt approximately 1% (AASHTO, 2009).

Since implementing the anti-icing strategy, MassDOT has substantially reduced its use of sand, especially in Districts 1, 2 and 3. MassDOT used a total of approximately 100,000 tons of sand within the last six years (FY11 to FY16) with the largest amount of sand used in FY15 (35,767 tons). This is approximately half of what was used in the previous six years (FY05 to FY10), at approximately 218,000 tons.

3

Best Management Practices for Improving Road Salt Efficiency

3.1 Introduction

This chapter provides an update on various technologies, equipment upgrades, and policy changes that MassDOT has adopted to improve the effectiveness and efficiency of their winter maintenance program. Although liquid deicers have been used to some degree in the past, MassDOT more broadly adopted the use of liquid deicers starting in the 2010/11 (FY11) winter by requiring contractors to have pre-wetting equipment.

Other new technologies adopted include use of computer controllers, pavement condition sensors, enhanced plow blades, and RWISs, described below. These newer technologies help to either better determine when deicer material is needed, improve the material usage tracking and reporting, and/or improve road surface conditions during winter weather. Reducing labor and equipment demands as well as potential adverse environmental impacts are also key areas of focus.

This chapter also compares the advantages and disadvantages of alternative deicers. MassDOT has adopted or evaluated the use of various deicers as well as other technologies to improve roadway safety, reduce costs, and minimize potential environmental impacts.

3.2 Anti-Icing Techniques

Although plowing remains the primary means of clearing snow from roadways, plowing alone will not prevent roads from becoming icy during winter weather events. The use of deicing materials is an essential part of any winter maintenance program to lower the freezing point as moisture accumulates on the road surface. Otherwise, water derived from fog, rain, freezing rain, snow or melting snow will freeze when pavement temperatures drop below 32°F resulting in icy and slippery conditions. Like other northeast states, MassDOT relies on sodium chloride in its solid, granular form as the principal deicer material because of its widespread availability and relatively low material cost. To be effective, road salt must dissolve into a brine solution to lower the liquid freeze temperature and prevent ice and snow from bonding to the road. Traditionally, winter maintenance supervisors would usually time the first road salt application to occur when there was sufficient

moisture on the road at the onset or immediately following the start of precipitation. Studies have shown that applying dry salt to dry pavement can result in 30% or more of the applied material either bouncing or being blown off the pavement due to the passing vehicles. Conversely, if supervisors wait too long to allow for moisture to accumulate on the road before initiating the first application, they face increased risk of accumulated snow or water freezing and bonding to the pavement. Once the snow and/or ice bonds to the pavement, it generally requires much more effort in terms of plowing and repetitive deicing applications to melt and/or dislodge the ice formation. This traditional approach of trying to time dry deicing material applications to occur when sufficient moisture was available is referred to as deicing strategy.

Anti-icing represents a more proactive approach by using liquid deicers to pretreat roads through direct applications and/or pre-wetting road salt at the time application to provide the necessary moisture to activate the salt and enable salt to stick to the roadway. Use of liquid deicers greatly enhances the efficiency and effectiveness of road salt and the ability to prevent snow and ice from bonding to the pavement. Bare pavement conditions can generally be achieved much sooner during or following a winter storm event.

As discussed in Chapter 1, MassDOT has used approximately 24% less road salt on an average annual basis in the last 5 to 6 years since anti-icing practices began in the winter of FY11 as compared to that used prior to FY11 under similar winter weather conditions. This magnitude of reduction is comparable to that reported by Minnesota DOT following implementation of anti-icing techniques (MinnDOT, 2012).

Perhaps the biggest incentive for using anti-icing techniques relates to the improved road conditions that generally result in fewer vehicle accidents. A significant decrease in the number of winter season vehicle crashes was observed in Connecticut over a seven-year period after anti-icing techniques were implemented in the 2006/2007 winter season relative to the previous seven years (Mahoney et al., 2015). An earlier study conducted by the Idaho Transportation Department reported a dramatic decrease in the number of vehicle crashes on a stretch of roadway in a mountainous region after converting to an all-liquid anti-icing policy for the designated stretch of roadway (Breen, 2001).

The following lists the various advantages and potential barriers to adopting an anti-icing approach. Details of the equipment needs and methods used to accomplish these techniques are provided in the next section.

Advantages of Anti-icing

- Allows more flexibility and time for supervisors and operators to treat roads prior to storm events
- Significantly reduces the potential for ice and hard "snowpack" to form on the pavement
- Allows supervisors to achieve reasonably safe road conditions earlier during or after a winter storm
- Can potentially delay the "call-out" of the full spreader fleet resulting in labor savings
- Typically increases vehicle mobility during winter storms and reduces the number of vehicle accidents
- Often reduces the number of deicing applications and plow passes depending on storm duration
- Often results in less seasonal usage of road salt depending on the winter weather conditions

Potential Barriers to Anti-icing

- Requires upfront investment for liquid deicer application equipment and storage facilities
- Requires additional equipment operation, maintenance and calibration processes
- Requires additional weather forecast and pavement monitoring and training to ensure liquid deicer applications, especially pretreatment applications, are done under appropriate conditions
- May accelerate corrosion of equipment and infrastructure depending on the materials used

Liquid deicers are mainly used to increase the effectiveness of granular road salt, rather than replace road salt. Liquid deicers are not suitable by themselves for all types of winter weather and roadway conditions. Other solid form deicers, such as calcium magnesium acetate (CMA, are available but are more expensive, as discussed earlier. For this reason, granular road salt remains the primary deicing material used. The amount of salt contained in liquid deicers represents a small fraction of that applied through regular road salt. In recent years, MassDOT has used, on average, approximately 1.4 million gallons of magnesium chloride ($MgCl_2$) and 250,000 gallons of liquid brine per year. With salt concentrations in liquid deicers of approximately 30 and 23% by weight, respectively, the amount of salt applied through these liquid deicers translates to less than 2,000 tons of salt. This represents less than 1.0% of the average annual amount of granular road salt applied.

A recent survey of snow and ice managers in eight northeastern states confirmed that sodium chloride in its granular form is by far the most commonly used deicing material. The most common liquid deicers used for pretreatment and pre-wetting purposes consist of salt brine (sodium chloride dissolved in water), liquid calcium chloride (LCC) and/or liquid $MgCl_2$. Of the total amount of chlorides used in the surveyed states during the winters of FY2010 to 2014, only 0.3% was associated with liquid $MgCl_2$ and LCC, while most of the remaining applied chloride salt was associated with granular road salt (Mahoney et al., 2015). Granular sodium chloride costs significantly less than liquid deicers, is more readily available in bulk quantities and is easier to handle and store in large quantities as discussed further in Section 3.2.

3.2.1 Pre-Treatment

Pre-treatment involves direct applications of liquid deicer to the road surface prior to or in the early stages of a winter storm event using a tanker truck outfitted with a spreader bar with nozzles in the rear of the truck. The application rate for pre-treatment purposes is generally in the range of 20 to 30 gallons per lane-mile. Direct applications of liquid deicer across the travel surface provides a higher degree of initial protection against snow and ice bonding to the pavement. From a safety standpoint, preventing ice and snow from freezing to the pavement is perhaps the single most important factor that allows drivers to maintain vehicle control and shorter stopping distances. In addition, preventing snow and ice bonds in the early part of a winter storm event helps to avoid the additional labor required to remove the ice and/or hard snow pack after it has formed by plowing or trying to melt ice and displace the ice bonds through multiple road salt applications.

For pre-treatment purposes, MassDOT uses two types of liquid deicers throughout the state including a blended brine solution of 85% $NaCl$ and 15% $MgCl_2$ or liquid $MgCl_2$ at 30% concentration, meaning 3 parts $MgCl_2$ and 7 parts water. The blended brine solution costs approximately 50% less than liquid $MgCl_2$.

The amount of roadway "pretreated" prior to each storm can vary depending on the timing of the storm, number of tanker trucks available, and various road and weather factors. Pretreatment is generally not done during windy conditions, when there is excessive moisture or snow accumulated on the pavement or when temperatures are below 20°F. MassDOT currently has access to approximately 30 tanker-trucks to pre-treat approximately 10-35% of the roadway lane-miles in each district, depending on forecast and temperatures. Interstate roadways and RSZs represent the primary focus areas for pretreatment.

Since liquid deicers consist of dilute solutions (i.e., have lower salt content), there is generally a narrower range of weather conditions appropriate for pretreatment as compared to solid deicers. Pretreatment is generally not done if pavement temperatures are close to or rising above 32°F and there is a threat of rain. Similarly,

pretreatment applications are typically not performed if pavement temperatures are at or forecasted to be below 20°F because of threat of freezing. Pre-treatment requires more planning and consideration of various weather-related factors, to determine its appropriateness and effectiveness for each winter event.

Pretreatment typically delays the timing of the first regular road salt application because the initial "protective" layer is generally sufficient to prevent snow and ice from bonding in the early stages of a winter event. Over time, the deicing concentration left by pretreatment becomes diluted such that an application of the more concentrated, solid deicer is needed to prevent freezing. The time delay between pretreatment and when the first application is needed will depend on a number of factors including, but not limited to: precipitation type, intensity, time of day, and temperature. Pretreatment applications ultimately result in less overall road salt usage on a per storm and seasonal basis.

3.2.2 Pre-Wetting

Pre-wetting involves spraying liquid deicer on dry granular salt, usually at the end of the spreader truck chute during regular salt applications. This is accomplished by outfitting traditional spreader trucks with "saddle" tanks and spray nozzles fixed to the spreader chute just above the spinner. Pre-wetting activates salt by initiating the dissolution process, which makes it more effective as the solid material dissolves into brine much faster after application. Pre-wetting also helps road salt adhere to the roadway instead of bouncing or being blown off the roadway shoulder. Pre-wetting is performed on all MassDOT maintained roadways as all state and vendor-owned spreader trucks are required to have pre-wetting equipment. The liquid application rate for pre-wetting purposes is generally in the range of 8 to 10 gallons per ton of salt applied. For a typical two-lane road, this application rate works out to be approximately 1 gallon per mile for each application.

For pre-wetting, MassDOT mostly uses a commercial product called ProMelt Mag 30 INH, which consists of 30% liquid $MgCl_2$ in water with an amine corrosion inhibitor to reduce its corrosiveness. The amine additive typically consists of an organic-based complex fatty acid or carbohydrate and comprises less than 1% of the solution concentration. Previously, MassDOT used LCC for pre-wetting, but LCC was found to be too corrosive on equipment. The ProMelt product is approximately 70% less corrosive than the liquid $CaCl_2$.

As mentioned earlier, MassDOT revised its SICP policies and contractor agreements prior to the 2010/11 winter and required all vendors to have pre-wetting equipment prior to being called into service. To compensate for the added costs, contractor reimbursement rate for services were also increased. MassDOT also retrofitted its own trucks with the same pre-wetting equipment and increased their storage capacity for liquid deicers at the various depots. In just a few years, more than 80% of the contractors had closed-loop controllers installed and, thus, for consistency, MassDOT changed their policy in 2014/15 to require all contractors to have closed-loop controllers to be called into service. As discussed in Chapter 1, these policy changes are likely to account for much of the salt use reduction that has occurred in the last 5 to 6 years.

A Michigan DOT study revealed that as much as 30% of the applied salt may be lost due salt particles bouncing and scattering off the pavement when dry salt is applied to dry pavement. This leaves only 70% of the applied material available for deicing (Kahl, 2002). The added moisture provided by the liquid deicer during pre-wetting initiates the dissolving process, which allows the salt to "stick" the roadway. A recent Clear Roads report also reported that pre-wetting can reduce deicing material usage by 30% or more. Not only does the "wetted" salt stick to the road better but the lower "freezing point" from using liquid $MgCl_2$ also makes pre-wetted salt much more effective at lower temperatures (Nixon and DeVries, 2015).

3.3 Alternative Deicers

In the northeast and most snow-belt states, sodium chloride is the principal deicing chemical used to lower the freeze point temperature and prevent ice formation on paved surfaces. **Sodium chloride lowers the freezing point of water and prevents ice formation on paved surfaces.** To a lesser extent, CaCl_2 and MgCl_2 are also used, but mostly in liquid form for pre-wetting and pretreatment purposes. These chloride-based deicers are more commonly used because of their relative low cost and widespread availability.

3.3.1 Comparison of Alternative Deicers

Non-chloride deicers are typically comprised of organic-based compounds such as acetates, formates, urea, glycols or succinates usually derived from byproducts of the agricultural and/or food processing industry. These compounds are in the form of complex carbohydrate acids such as acetic acids or formic acids found in beet juice, corn based sugars, vinegars and pickle juice. Glycols and, to a lesser extent, urea are often used for aircraft deicing because of their low corrosive properties and even lower freeze temperatures compared to chloride based deicers, but are generally much more expensive.

Acetate based deicers generally include CMA, Potassium Acetate (KAc) and Sodium Acetate (NaAc). CMA is available in solid flake or pellet forms as well as liquid solutions. KAc is only available in liquid form. Organic based deicers are typically used to minimize corrosion impacts on major bridges or other metal-based infrastructure. Organic based deicers are generally less corrosive to carbonized steel, but still corrosive to galvanized steel (Shi et al., 2009).

Figure 3.1 presents a relative comparison of the estimated freeze point temperatures for common chloride and non-chloride liquid deicers in their liquid state at specific concentrations. For a deicer to be effective in melting snow or preventing ice from bonding to the pavement, it must dissolve into a liquid solution, even if it is initially applied in solid form. Once in solution, the lowest temperature at which the liquid remains a liquid and does not refreeze is referred to as the "eutectic" temperature, which varies for each deicer material and by concentration. The target concentration of KAc is 50% by weight which results in the lowest estimated freeze point temperature at approximately -70°F. Sodium chloride has the highest freeze point temperature of approximately -6°F at a concentration of 23%. Calcium chloride has the second lowest estimated freeze point temperature of -60°F at a concentration of 30% and magnesium chloride has an estimated freeze point temperature of -30°F at a concentration of 20%. The estimated freeze point of CMA is in between NaCl and MgCl at -20°F at a concentration of 32%.

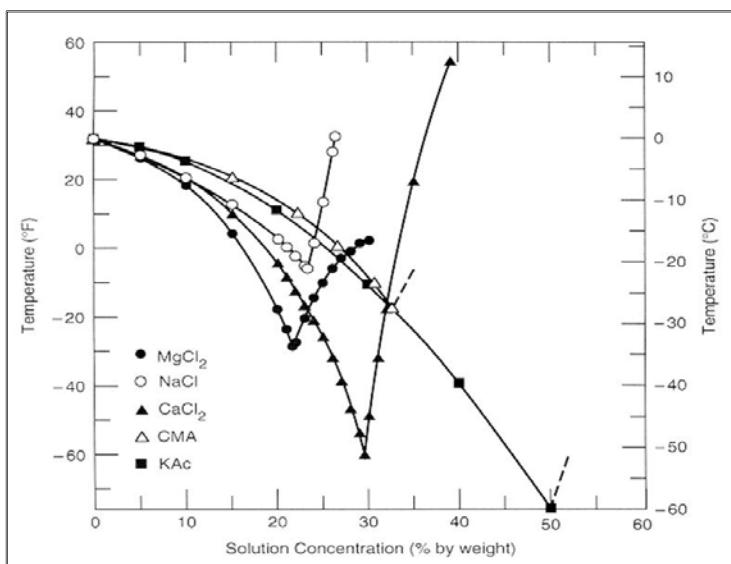
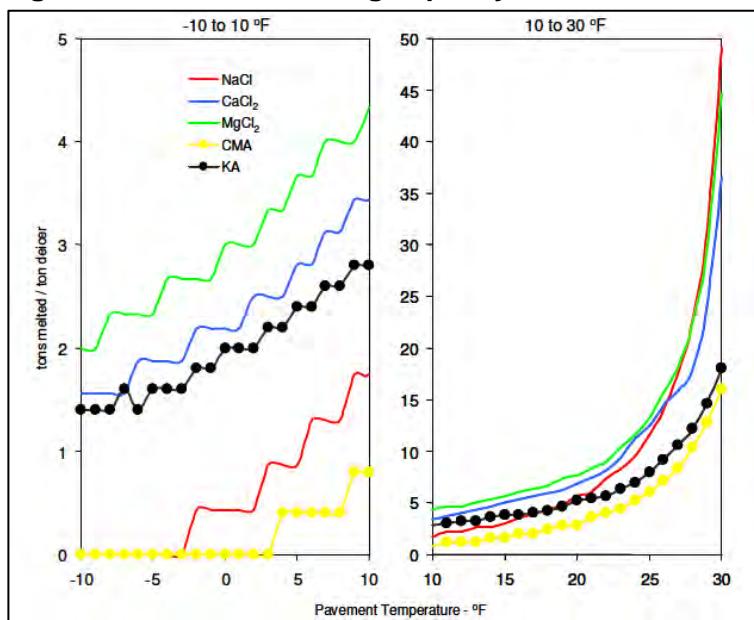
Figure 3.1: Freeze Point Temperature for Various Deicing Chemicals (Ketcham et al., 1996)

Figure 3.2 presents a relative comparison of the melting capacity (i.e., tons of ice melted per ton of deicer used) for various chloride and acetate-based deicers for a range of temperatures between -10°F to 10°F and between 10°F and 30°F. The difference in melting capacities are greatest at the lower temperature range, with MgCl₂, CaCl₂ and KAc generally having higher melting capacities and NaCl and CMA having similar lower melting capabilities. In general, winter maintenance professionals consider most deicers as being ineffective when pavement temperatures are at or below 10°F, regardless of whether applied in solid or liquid forms. At the higher temperature range, the various deicers have similar melting capacities and their performance increases exponentially at temperatures above 20°F and even more so above 25°F. CMA and KAc appear to have an upper limit to their melting capacity when temperatures are near 30°F.

Figure 3.2: Relative melting capacity of chloride and acetate based deicers

(adapted from Kelting and Laxon 2010)

A survey of winter maintenance personnel from 23 state transportation agencies conducted in 2015 indicated that sodium chloride, magnesium chloride and calcium chloride are by far the primary deicing chemicals used. The latter two chemicals were used mainly in liquid form. Several agencies used various proprietary blends of chloride deicers with organic additives. These products include Ice Slicer, GeoMelt and GeoBrine. Only Arkansas reported using a pure organic compound consisting of beet juice (accessed online at <http://sicop.transportation.org/Documents/SICOP-Survey%20Summaries/2014-15%20Winter%20Maintenance%20Survey%20Summary.pdf>.)

This is consistent with a previous state-by-state survey, conducted in 2007, which revealed very limited use of organic-based deicers relative to sodium chloride and sand. Ninety-three (93) % of the total 8.5 million tons of deicer and abrasive material applied in 2003 within 28 US States and four Canadian provinces consisted of sodium chloride and sand (or other abrasives). The other 7% consisted of CaCl_2 , MgCl_2 , CMA and KAc as well as other proprietary or organic products. Use of CMA and KAc represented less than 1% of the total deicer usage. North Dakota and Utah were the only states that reported use of KAc.

MassDOT has first-hand experience with using CMA when it was used back in the late 1980's on a 1-mile section of Route 25 in Plymouth to assess whether CMA may be a viable alternative to using road salt in this area. District personnel reported that not only did it result in a large cost differential for materials, but CMA also took more time to react following applications and was less effective at colder temperatures than granular road salt. At times, additional regular salt applications were needed to alleviate hazardous road conditions. The average annual cost of using CMA on this one-mile stretch of roadway was reported to be \$75,000 per year, which was approximately 20 times the cost of using sodium chloride. A Wisconsin DOT study reported that CMA application rates need to be 1.2 to 1.6 times greater than that of salt to achieve the same results (Shi et al., 2009).

New Hampshire Department of Transportation (NHDOT) uses KAc as part of a Fixed Automated Spray Technology System installed on the I-89 bridge deck that spans the Connecticut River between New Hampshire and Vermont. The District Engineer had the following comment regarding its performance, when interviewed for an article published in the *Interstate Water Report* by New England Interstate Water Pollution Control Commission (Hockbrunn, 2010).

"For the cost, it certainly didn't work 30 times better than salt," he said. "The freeze point is so low, in the minus-70°F range, that there's always some residue out there. In a cold storm where the snow normally blows right off, the snow instead sticks to the deck, then the snow wets up and more snow gathers, it gets slippery, the system sprays, and the cycle continues. It creates its own problems sometimes. It certainly sprays at least as much as we think is necessary and then some. It's really most helpful when nobody is out and around. If there are freezing fog conditions at 2:00 in the morning and nobody knows about it and the deck freezes over, this would address that, whereas we would have to wait for someone to call us after a crash."

Table 3.1 provides a comparison of estimated material costs for various chloride and non-chloride deicers based on information presented in the Connecticut DOT Report (Mahoney et al., 2015). The reported costs for chloride deicers are very similar to those reported by MassDOT. Based on this information, sodium chloride is by far the least expensive deicing material on an estimated cost per lane-mile. The cost per lane assumes liquid and solid deicers are applied at a rate of 30 gallons and 240 lbs per ln-mi, respectively, consistent with MassDOT guidelines. CMA is estimated to be the most expensive and is roughly 27 times costlier than conventional road salt. Sodium formate and urea are 6 to 9 times costlier than regular road salt. Although these organic-based deicers are reported to be less toxic and less corrosive to steel components, they can still

pose serious environmental risk with respect to oxygen depletion and have varying corrosive effects on infrastructure as discussed in more detail in next section.

Table 3.1: Relative Estimated Material Cost on a Per Unit and Lane-Mile Basis

Deicer Type	Material	Available Form	Estimated Material Cost ¹	
			Per unit	Per lane-mile*
Chlorides	Sodium chloride	solid	~ \$70 / ton	~ \$8.4
		liquid	~ 15 cents /gallon	~ \$4.5
	Magnesium chloride	liquid	~ \$1.20 / gallon	~ \$36
	Calcium Chloride	liquid	~ \$1.60 / gallon	~ \$42
Acetates	Calcium Magnesium Acetate	solid, flake	~ \$1,900 / ton	~ \$228
	Sodium Acetate	solid	~ \$1,700 / ton	~ \$204
	Potassium Acetate (50% liquid conc.)	liquid	~ \$5.50 /gallon	~ \$165
Formates	Sodium Formate	solid	~ \$400 / ton	~ \$48
	Potassium Formate	liquid	na	--
Urea	Urea	solid	~ \$490 / ton	~ \$58.8
Glycerol/Glycol	Propylene Glycol	liquid	~ \$5 / gallon	~ \$1,200
Succinate	Potassium Succinate	liquid	~ \$2.50 / gallon	~ \$75
Sand	Sand	solid	\$10 / ton	~ \$1.2

Notes: Cost information for organic deicers is based on 2015 Connecticut DOT Report prepared by the Connecticut Academy of Science and Engineering. Chloride deicer information is based on actual MassDOT data. Estimated cost per lane-mile was based on an assumed application rate for solid and liquid deicers was 240 lbs/lane-mi and 30 gallons/lane-mi, respectively.

The costs are fairly similar amongst the various liquid deicers except for KAc, which is approximately five (5) times more costly than liquid MgCl₂ and 30 times more expensive than sodium chloride brine solution. Sodium chloride in a brine solution is by far the least expensive deicing product. Ultimately, the overall material costs depend on the solution concentration and the overall amount used to achieve the same level of service.

A study conducted by Kelting and Laxson (2010) suggests that the "hidden" costs of using sodium chloride associated with potential corrosion and environmental impacts are potentially much greater than the material cost differential between chloride and non-chloride deicers. The study notes that the potential corrosion and environmental costs are highly variable and the factors involved are very site-specific as discussed more in Chapter 4. It also assumes that non-chloride deicers are as readily available as regular road salt and as effective as sodium chloride, which is not always the case. As discussed earlier, converting to a non-chloride deicer is not a feasible option for MassDOT since it would increase the annual winter maintenance budget by hundreds of millions of dollars just in material cost alone. Nonetheless, the study does emphasize the importance of using advanced technologies and efficiency measures to be most efficient with road salt use.

There are hundreds of various proprietary products consisting of different blends of chloride and organic based compounds. These mixed products seek to capture the best performance properties of each compound. Road salt pre-wetted or sprayed with an organic-based product represents common commercially-available products. Examples of these products include Ice B Gone™ Magic, Clearlane™ Enhanced Deicer and FireRock™ Caliber 2000. The organic additive, which is typically a molasses or beet juice, is used to help make the salt "stick" to the road, boost effectiveness at lower temperatures, and reduce the corrosiveness of the chloride salt. These products generally cost 15 to 20% more than regular road salt and are typically used by municipalities and private contractors that purchase smaller quantities of deicer materials and/or prefer not to invest in pre-

wetting equipment and liquid storage. These products also pose similar environmental concerns as the other organic compounds discussed further below.

3.3.2 Environmental Effects of Non-Chloride or Agricultural Based Deicing Chemicals

As described in Chapter 2, non-chloride or organic-based deicers have received a great deal of attention as possible alternatives to chloride deicers for winter maintenance. Non-chloride deicers are generally viewed as being more "eco-friendly" or less toxic because they are generally comprised of organic-based compounds such as acetic acids (e.g. CMA or KAc) or food processing or fermentation byproducts such as beet juice or molasses. Organic or agricultural-based deicer products are more commonly used for airplane or airport deicing because of their lower corrosion potential and greater effectiveness at lower temperatures, but are used only in select areas for roadway deicing. This is primarily due to the cost differential, but also due to performance and operational factors such as relative availability and ease of transport, storage and application. Most organic or ag-based products are in liquid form, except for CMA, and, thus, are mostly used for pre-wetting or pretreatment purposes rather than as a replacement for road salt.

Organic-based deicers have been shown to be generally less toxic to aquatic life, roadside vegetation and human health, but the organic component of these deicers can cause a high biological oxygen demand (BOD). Micro-organisms feed on the available carbohydrates and sugars in soils and receiving waters which results in low levels of oxygen (Muthumani et al., 2015; Corsi et al, 2012; Wegner and Yaggi, 2001; and Horner, 1998). Reported BOD levels for CMA and other organic based deicers have generally ranged from 500 mg/L to over 100,000 mg/L, depending on the material and concentration, which are BOD levels that are comparable those typically observed in sanitary wastewater and could have a significant effect on dissolved oxygen levels in receiving waters (Levelton Consultants Ltd., 2007). Organic-based deicers also typically contain elevated levels of nutrients such as phosphorus and nitrogen, depending on the type of organic material used in the product formation, which could stimulate algal growth and accelerate eutrophic conditions in lakes, ponds and coastal estuaries (Albright, 2005).

The potential impact of oxygen demand in nearby water bodies depends in large part on the water body size, its inherent flow and/or flushing rate, and the amount of highway runoff it receives. Obviously, smaller lakes and ponds located directly adjacent to treated roadways will be more vulnerable. Lakes or ponds with relatively longer residence times (low flushing rates) and/or water bodies with low dissolved oxygen levels due to other organic and nutrient inputs will be more vulnerable. Many urban lakes and ponds in heavily developed areas of the state typically have low dissolved oxygen levels due to excess nutrient inputs conveyed by stormwater from impervious areas and managed turf. The assimilative capacity of receiving waters to receive additional oxygen demanding substances will need to be determined based on site-specific conditions. Since dissolved oxygen levels tend to be higher with colder water temperatures during winter months, this may serve to partially mitigate the oxygen demand during the biodegradation of these compounds. Temporary anaerobic conditions may occur in roadside soils due to the microbial biodegradation in the soils (Shi et al., 2009). A potential mitigating factor is that CMA and other organic products have a relatively short, half-life of days or weeks and, thus, does not accumulate or persist in the environment once biodegraded.

3.4 Equipment and Technological Advances

Various equipment and technology innovations have been developed in recent years to improve weather forecasting, remotely monitor roadway conditions, improve deicing material effectiveness, and better track and record material usage. These innovations have generally made winter maintenance activities more effective and efficient. The list of innovations for each of these categories are provided as follows:

Innovations that Improve Decision-Making

- Mobile pavement temperature sensors
- Pavement surface friction monitors
- Improved weather forecasting tools and services

Innovations that Improve Efficiency and Material Use Tracking

- Computer spreader controllers
- Enhanced snow blades, tow plows, and other spreader type modifications
- Global Positioning System/ Automatic Vehicle Locator (GPS/AVL) Equipment
- Front-end loader weighing systems
- Pavement technologies
- Salt slurry application trucks
- Electronic signage

The following provides a summary description of each of these improvements based on a review of the available literature and research.

3.4.1 Mobile Pavement Temperature Sensors

MassDOT has outfitted some of their vehicles with mobile pavement temperature sensors to supplement the additional data collected by the RWIS stations. These temperature sensors, typically mounted to a vehicle's bumper or side view mirror, display road surface temperature data to the driver via an in-cab display unit. This allows operators to monitor real-time pavement temperatures for various roadway conditions. Pavement temperatures are often quite different than the air temperature as pavement temperatures respond more slowly to changes in air temperatures and often reflect what the prevailing air temperatures were over the last 48 to 72 hours rather than the current temperatures. District personnel report that pavement temperature sensors greatly improve their ability to determine when deicing materials are needed and what materials should be used. Missouri DOT reported saving over \$185,000 in one year in just material costs alone by installing 50 mirror-mounted Sprague Road Watch sensors (Shi et al., 2006). Periodic calibration is necessary to ensure continued accuracy of the sensors.

3.4.2 Road Weather Information Systems (RWIS)

MassDOT continues to expand its fixed and mobile station (RWIS network) to collect and transmit weather data as well as road condition data. MassDOT currently has more than forty (40) fixed RWIS stations throughout the state. Many of the stationary stations have closed circuit cameras that allow for real-time, visual monitoring of road and weather conditions. The type of data collected includes air and pavement temperatures, wind speed, relative humidity, moisture and precipitation. Some RWIS systems have chemical concentration or conductivity

sensors. The RWIS data helps to eliminate some of the “guesswork” in determining the status of road conditions and to make more informed decisions in determining when chemical applications may be needed and what type of deicer should be used.

Most recently, MassDOT invested in a new generation of mobile, truck or trailer mounted RWIS devices that utilize lasers for liquid and ice detection as well as friction detection. The advantage of mobile RWIS devices is that they are less intrusive by not having to embed sensors in the pavement (see Figure 3.3). These more advanced weather and road surface sensors are manufactured by the Vaisala Group, headquartered in Finland, and can be mounted on either overhead poles or vehicles to provide real-time pavement conditions including temperature and the presence of water, black ice and white ice, and surface friction or “grip”. These sensors can detect the presence of ice crystals before they cause the road to become slippery. District personnel can closely monitor road conditions that can create a hazardous driving surface. These non-intrusive devices make for easier installation and do not require disruption to pavement.

Pavement embedded sensors are more vulnerable to damage and/or malfunction due to the vibrations and weight of passing vehicles. Like most outdoor instruments, RWIS sensors and related hardware generally require frequent maintenance.

Studies have reported that the benefits of RWIS typically far outweigh the costs with estimated benefit-to-cost ratios ranging from a low of 2:1 to a high of 10:1 (Rall, 2010). The potential benefits are mostly linked to reduced labor costs as supervisors are more able to accurately time when crews and materials are needed with the more detailed site-specific weather information. RWIS data reduces the guesswork in deciding when to apply materials and eliminates the need to “hedge against uncertainty” when location-specific information is limited, especially in the early stages of a storm event. RWIS data can provide a level of certainty in the decision-making process when pavement temperatures are hovering around 32°F and/or if the chemical concentration sensor indicates that there is still residual deicing chemical on the pavement. In addition to labor and material cost savings, the use of RWIS can provide an early warning system when linked to electronic messaging signs, which can alert drivers of changing weather and perhaps reduce vehicle crashes (Rall, 2010).

3.4.3 Material Decision Support System (MDSS)

Material Decision Support System (MDSS) is a software application system that integrates RWIS data, weather forecast and road surface information to guide maintenance personnel in determining when and what winter maintenance activities should be done to achieve a desired roadway condition. The MDSS was initially developed in 2000 under a cooperative agreement with the Federal Highway Administration’s (FHWA) Office of Transportation Operations and the National Center for Atmospheric Research. More than twenty (20) states have reported using some form of MDSS technology (NYSDOT, 2014). The MDSS technology can be used as a forecasting tool to help decide when to schedule maintenance activities and/or what material and rate would



Figure 3.3: Vaisala Road Surface Sensors (DST111 & DSC111)

best achieve a desired level of treatment. The MDSS can also be used as a retrospective evaluation or training tool to assess how a different approach, activity or material selection might have affected roadway conditions.

Like any forecasting tool, the accuracy of the information provided by the MDSS depends on the geospatial coverage, timeliness, and representativeness of the data. Perhaps one downside of the MDSS is that it is data intensive and any disruption in the data collection process or service can limit the usefulness of the MDSS. The MDSS is not intended to supersede or replace the need for winter maintenance supervisors to make the final decisions of appropriate maintenance activities since winter weather conditions can be highly variable and the MDSS may be influenced by non-weather-related factors.

Perhaps the MDSS is most useful in allowing decision makers to reflectively compare how different materials, application rates, and/or timing of applications as well as other activities (i.e., plowing) might have affected road conditions given current weather conditions in either real-time or as post-storm analysis. These analyses enable maintenance personnel to select other options or a sequence of activities that can be used to achieve a desired outcome and/or retrospectively evaluate the potential consequences of other "what if" scenarios utilized under the same weather and road conditions. This may benefit transportation agencies in evaluating how other operational choices, such as reduced applications or the use of other chemicals, may have affected road conditions while balancing the goals of safe roadway conditions and environmental concerns.

3.4.4 Closed-Loop Computer Controllers

MassDOT has steadily increased their use of closed-loop controllers to apply granular road salt. Use of these devices initially started in 2010/11, through contractor incentives by offering a higher reimbursement rate for vendors that use some form of closed-loop controller as shown in Figure 3-4. These incentives resulted in approximately 50 to 80% utilization rates across the various regions in the State. More recently, MassDOT revised their winter maintenance policies and contractor agreements to require all spreader trucks, both state-owned and hired, to have a closed-loop controller prior to being called into service. MassDOT has retrofitted their state-owned spreaders to be equipped with these controllers. Contractor reimbursement rates have also been revised with this equipment policy change.

Closed-loop controllers adjust application rates by both vehicle speed and conveyor auger speed at the back of the truck, which results in much greater control and consistent applications of deicer material. The latter adjustment is a major improvement as the feed-belt or auger speed changes over time due to wear and tear,

temperature variations and performance fluctuations in the spreader's hydraulic fluid. This added "feedback" results in more consistent and uniform applications across various routes. One recent case study reported that the use of closed-loop controllers resulted in a 30% reduction in material usage as compared to conventional spreaders due to the more consistent applications adjusted for truck speed and spreader mechanics. Adjustments for vehicle speed alone, account for most of the material savings. Most controllers integrate GPS/ AVL functions as well as can be programmed to adjust application rates based on pavement temperatures measured by mobile temperature sensors.



Figure 3.4: Bosch Rexroth CS-550 CompuSpread Controller

These controllers also have data recording and reporting capabilities that can report key data such as material usage, number of lane-miles traveled, and number of applied miles (based on when the auger was engaged) and an average application rate. At the end of each storm, MassDOT requires operators to report this data to district personnel using a standard reporting form. The accuracy of the data provided depends on how well the controller was set to reflect the settings used during the calibration process. For the most part, MassDOT has found that the controller data appears to be reasonably accurate, however, reporting errors can arise if the operator is not diligent in adjusting the controller to proper settings. Occasionally, discrepancies emerge in terms of how much material was reported to be used compared to how much material is left in storage. These discrepancies are most likely due to controller settings during operation being different from those used during the calibration process. For example, the controller settings may change whether the application is for one lane or two lanes, or if the gate height was changed due to cleaning or other maintenance issues. MassDOT has initiated several actions, policy changes, or pilot studies to help rectify these issues.

District 1 recently installed a wireless download station to retrieve data electronically from select spreaders used on portions of I-90 in western Massachusetts. Obtaining the electronic data log allows review of the material application over time rather than just at the end of the storm which provides greater review and checks against vehicle travel activity over time. This also helps to reduce human error resulting from transcription errors in the reporting. The downloading capability, however, is limited somewhat by the fact that hired contractors utilize various types of controllers from several manufacturers, which utilize different computer coding and slightly different reporting methods and functionality. MassDOT is developing a universal and consistent method to collect this data electronically through a cloud-based system that directly reports vehicles data usage parameters to MassDOT at specified time intervals.

Starting in the winter of 2016/17, MassDOT revised its contractor agreements to require Equipment Calibration Facilities to mark the height of the gate opening used during calibration process on the back of the spreader body with illuminating tape. This helps the MassDOT calibration teams in each district check to see if the current gate opening on each truck is consistent with the gate opening used when the controller was calibrated prior to the season. For a variety of reasons, operators may adjust gate openings over the course of the season and this can lead to inaccurate salt usage data being recorded.

MassDOT recently initiated a pilot study to evaluate how the use of a front-end loader scale which records the volume of material loaded into each spreader truck compares to the material usage reported by the closed-loop controller. The loader scale provides another means to measure the amount of material used by each spreader and on each spreader route. More details on how the front-end loader scales will be used are described below. Since the 2016/17 winter is the first season loader scales are used, the results and performance of these devices will be reported in future SICP ESPR and related Annual Reports.

MassDOT requires that all hired-equipment operators submit Certificates of Calibration for each piece of equipment used for deicing applications before winter operations begin. Hired contractors are also required to retain a copy of their calibration form that certifies that their equipment has been calibrated prior to each season. A copy of this calibration form is provided in **Appendix D**. State owned spreaders are also periodically calibrated and checked to ensure consistency and accuracy of material usage.

3.4.5 GPS/AVL Equipment

MassDOT initiated a pilot study starting in the 2016/17 winter to utilize GPS/AVL devices on state and hired material spreading equipment that service roads in the Dedham-Westwood Water District (DWWD) area. The purpose of the pilot study is to evaluate the effectiveness of this equipment to track material usage, perhaps optimize spreader routes, and compare application frequency within the limits of public well contributing area. MassDOT will evaluate the cost-benefits of the additional software and hardware needs as well as the feasibility of expanding use beyond the pilot study. In addition to the additional hardware and wireless infrastructure, processing and managing the data will require additional personnel time. Ultimately, it may be possible to program the GPS enabled controllers, using georeferenced data, to automate applications and/or prevent redundant or unnecessary applications based on local weather and road data. GPS/AVL equipment can provide a wide variety of information including:

- Material application rates
- Amount of material applied
- Road and air temperature
- Vehicle position and speed

Information collected from GPS/AVL equipment may provide data that can be used as potential performance metrics such as amount of time spent to complete routes or how road conditions, locations and orientation may affect deicing material demand in order to optimize the plowing with timing and application of materials on roadways. GPS/AVL equipment that is integrated into MDSS software can greatly improve data collection for planning purposes and monitoring of plan implementation.

3.4.6 Front-End Loader Weigh Scales

MassDOT recently pilot-tested the use of computerized front-end loader scales at select depots to evaluate whether these devices might improve the tracking of deicer material used by vehicle and spreader routes. Currently, these devices can help to validate the material usage reporting and perhaps identify some of the variables involved with tracking material usage using closed-loop controllers and/or with recording bucket loads manually by front-end loader operators. Various factors associated with these methods can lead to errors and/or significant differences in reporting results between methods. Loading spreader trucks with front-end loaders is a consistent and essential step to the application process of granular road salt. Front-end loader scale manufacturers claim these devices can attain 1% accuracy if properly installed and calibrated. This level of accuracy makes these devices very appealing in improving the material usage tracking and reporting process. These devices could also be used as another calibration check to identify spreaders that appear to be reporting erroneous data due to improper controller settings, equipment malfunctions or incomplete calibration.

The added cost to implement and maintain these devices statewide represents a significant upfront cost that may need to be phased in over time. The up-front cost to install these devices ranges from \$12,000 to \$15,000 per loader, and approximately 20 to 30 front-end loaders are used in each of the six (6) districts. Additional up-front costs will be needed to install the wireless routers and related hardware to collect data electronically. There is also additional annual operation and maintenance costs and personnel time required to maintain, calibrate, and operate these devices. The results of the additional ongoing testing will help to determine whether the potential benefits of front-end loader scales to improve the material usage reporting process will outweigh the potential added costs to install these devices.

3.4.7 Improved Plow Blades

Plowing represents the principal means of removing snow and ice from the roadway, particularly during larger snow events with cold temperatures and fluffy snow. Any plow blade improvements that can make plowing more effective can lead to reduced labor and equipment costs as well as less deicing chemical usage. Newer plow blades have become lighter, more flexible and incorporate either segmented blade tips or multiple blades to achieve greater road contact and better performance than the traditional fixed steel blades. The JOMA 6000 blades, made by Black Cat Blades of Sweden, consist of segmented tungsten carbide inserts encased in rubber, which is more flexible, quieter, and conforms better to the contour of the road. NHDOT recently experimented with the use of these blades and found they not only cleared the road better but the blades were quieter, had less vibration and greater longevity than regular carbide steel blades. The constant vibration associated with regular steel blades contributes to greater operator fatigue. The ability to replace sections of the plow blade instead of the whole blade was reported as another major advantage. Illinois DOT also reported that the JOMA 6000 blades appeared to clear the road better and were quieter than the conventional blades. The new blades cost 2.5 to 3 times more than the standard carbide blades, but last twice as long as traditional carbide steel blades which generally makes up for the added upfront costs (Fay et al., 2015).

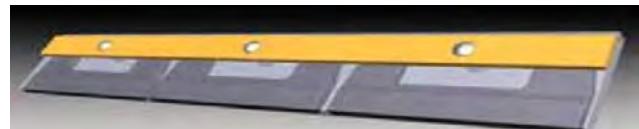


Figure 3.5: Segmented Plow Blade

Ohio DOT also found that the JOMA blades were superior to standard blades, outlasting steel blades by a greater than 4:1 ratio, and the reduced vibration resulted in less operator and equipment fatigue, as well as less wear on roadway pavement. Iowa DOT also found that JOMA 6000 blades lasted 3 to 4 times longer than standard carbide blades. Even though the cost is twice as much as standard blades, the added durability and improved performance was sufficient to warrant purchase of additional plow blades (Iowa DOT, 2009).

Maine DOT recently experimented with another new plow blade referred to as the Kuper-Tuca SX36™ ceramic blade. MaineDOT found that the Kuper blades were quieter, had less vibration, and lasted 2.25 times longer than standard blades. However, these blades cost approximately five times as much as standard carbide blades so they proved to be a less cost-effective alternative to standard carbide plow blades (Colson, 2010).

Other recent plow-related innovations include the use of under-belly plows, which are plows that are installed underneath the main body of the truck. The force of the added truck weight on top of plow blade generally results in greater road surface contact, better scraping ability, and a cleaner road surface. These plow blades are only appropriate for certain types of trucks that have the required minimum vertical clearance and wheel span. As mentioned earlier, plowing does not eliminate the need for deicing applications to prevent moisture from freezing on the road surface.

3.4.8 Tow Plows

Tow plows represent another recent innovation that allows plow operators to clear two lane-widths in one vehicle pass. A tow-plow consists of a trailer-mounted plow that is towed behind a standard plow truck (see Figure 3.6). Tow-plows are also typically equipped with a spreader hopper or liquid tank with spray to apply materials. Tow-plows reduce the number of operators, man-hours and fuel costs by eliminating the need for another plow truck and operator when in use. MassDOT now has seventeen (17) tow plows that are used mostly on multi-lane Interstate roadways throughout the state.

District personnel report that in addition to reducing labor and equipment costs, use of tow plows allows greater flexibility in deploying available plows since fewer plows are needed for a given area while maintaining

the same or a better level of service. Tow plows generally cost about half as much as a fully outfitted spreader truck, which reduces equipment costs as well.



Figure 3.6: Tow Plow in Action (Courtesy of MassDOT)

Over a dozen states are now using tow plows including the northern New England states of Maine, Vermont and New Hampshire. Other states using tow plows in the last several years include Iowa, Utah, Wisconsin, Michigan, Minnesota, Missouri, Ohio, and Pennsylvania. In general, winter maintenance professionals have reported that the use of tow plows frees up other trucks as fewer plow trucks are needed to clear the same amount of roadway (Fay et al., 2015). Tow plows also reduce vehicle emissions.

3.4.9 Salt Slurry Spreaders

Salt slurry applicators generally combine the beneficial aspects of pretreatment and prewetting by increasing the liquid to solid ratio and applying granular road salt material in a semi-solid or liquid paste. This salt slurry results in a more activated and concentrated application that "sticks" to the roadway. Slurry applicators apply more of a "paste-like" substance by grinding the salt into finer particle sizes and using a higher liquid content of up 70 to 90 gallons per ton of salt. The material is generally applied in a windrow fashion but the application width can vary depending on the spreader type. Initial testing of an Epoke slurry spreader in Ohio indicated that 12% less salt was used compared to a conventional spreader (Fay et al., 2015). Maine DOT recently tested a Munroe type of salt slurry applicator and found that the applications delivered a quicker response time as compared to pre-wetted salt because the material was already in a near liquid or dissolved form. Maine DOT reported there was some challenges in maintaining the liquid content, but it may have been due to a constrained liquid pump capacity. The increased level of performance relative to pre-wetted salt applications depends on pavement temperatures and precipitation intensity. Maine DOT also reported that the smaller salt granules created by the slurry applicator dissolved more quickly and the crushing or grinding of regular road salt into smaller particles should be considered for future use regardless of whether or not the slurry applicators are used. (Maine DOT, 2009).

3.4.10 Electronic Signage

MassDOT has greatly expanded its use of variable message signs to warn motorists of pending inclement weather conditions, roadway conditions, traffic delays, and reduced speed limits. MassDOT currently has over sixty (60) variable messaging signs located throughout the state. The messaging is controlled by the HOC and focuses on providing up to the minute local and regional roadway, traffic and weather information, and to some extent, is integrated into the RWIS weather and roadway information system. District personnel have anecdotally observed that the signs have had a positive effect on modifying driver behavior and traffic congestion as motorists either adjust traffic speeds, seek alternative routes or stay at home to telecommute on inclement winter weather days perhaps as a result of the warning messages. These efforts are part of a growing field of "SMART" intelligent technology using data from a variety of sources that are integrated into Intelligent Traffic Management Systems.

3.5 Various Pavement Technologies

The type of pavement used on a highway can have a substantial effect on highway safety related to the amount of water remaining on the highway and to the removal of snow and ice. One of the newer innovations in pavement technologies relates to various epoxy-type, spray or roll-on surface overlays. Such pavement overlays have been used for several years mainly for purposes of traffic control and delineating critical areas such as crosswalks, traffic islands, turning lanes, etc. However, more recently, pavement overlays have been developed to specifically improve surface friction on roadways and increase skid resistance. There is limited data in terms of the potential costs/benefits of these pavement overlays and their durability and effectiveness with respect to reducing deicing material usage under a variety of roadway conditions, especially on high volume interstate highways.

SafeLane® is a proprietary pavement overlay product manufactured by Cargill, Inc. It is a porous aggregate mix that is designed to retain previously applied anti-icing chemicals to allow for reactivation with increasing moisture during storm events. This provides ongoing anti-icing benefits from storm to storm. The aggregate also increases the friction or skid resistance during both dry and wet weather and is intended to be used in areas that may have higher than normal accident rates due to steep grades or poor road geometry.

The Vermont Agency of Transportation (VAOT) tested the SafeLane® pavement overlay in 2007 and 2008 on three roadway segments that had much higher than normal accident rates during winter months. Two of the segments were on relatively steep grades where vehicles, particularly larger multi-axle vehicles, had difficulty gaining traction during winter weather events. The third roadway section was located along a bridge approach where vehicles often made sharp turns directly after the bridge at a difficult angle. From a safety standpoint, the SafeLane® overlay appeared to reduce the number of accidents and provided greater traction for larger vehicles on the steep grades during inclement winter weather. However, the amount of deicer material used did not dramatically change as normal winter roadway maintenance activities were performed along the tested roadway segments. The SafeLane® overlay was not very durable and began to deteriorate after two seasons. VAOT is not planning any future use of the SafeLane® overlay until the aggregate material used in the overlay is proven to be more durable and has a longer lifespan (Kipp, 2014a).

Pavement overlay products are costly to install and their durability and longevity is highly dependent on the quality of the underlying pavement and the uniformity of road surface conditions at the time of installation. One of the added benefits is that the epoxy coating minimizes the intrusion of chlorides into the underlying pavement surface and, therefore, could reduce the amount of chloride reaching the steel rebar in bridge decks.

VAOT also tested a different type of pavement overlay, called Tyregrip®, on a stretch of VT Route 9, a two-lane roadway in the Town of Woodford in 2009. This product is designed to provide greater friction or skid resistance rather than retain anti-icing chemical. The pavement overlay is composed of a highly modified, two-part epoxy resin binder and surfaced with calcined bauxite aggregate to provide enhanced friction. Its performance or level of benefit in this case was measured in the comparison of vehicle accidents prior to and following the overlay installation. In the three years prior to installation, this roadway segment had over a dozen crashes compared to only one reported crash in the three years after installation. The overlay did increase traction and reduce vehicle accidents during the short period of use. However, a year after installation, the overlay began to deteriorate, and after three years, VAOT decided to pave over the overlay because the material had degraded so badly. VAOT is not likely to use this pavement overlay in the future. The deicing

material application rates on the overlay segment were the same as that used on adjacent roadway sections. The roadway sections were too small to warrant changes in winter maintenance operations. (Kipp, 2014b).

The pavement overlay technology appears to improve pavement friction and potentially reduce vehicle accidents but is not likely to gain widespread use because of material durability issues. The cost-benefit of installing and maintaining these overlays to potentially reduce the number of vehicle crashes in accident-prone areas will need to be determined on a case-by-case basis. More data is needed to fully evaluate the potential costs and benefits of using these products.

As reported in the 2012 ESPR, in the mid-1980's, MassDOT (at the time MassHighway) experimented with two pavement technologies known as Vergilimit™ and PlusRide. These products consist of patented chemical or physical modifications to bituminous pavement that were designed to improve the roadway surface conditions and potentially reduce deicing chemical needs during winter months. Vergilimit™ consisted of a pavement overlay that encapsulated calcium chloride into linseed oil into the top pavement course surface. As the surface wears from passing vehicles, small quantities of calcium chloride are released to create a thin film of calcium chloride brine solution on the road to prevent snow and ice from bonding to the pavement.

The results showed positive effects early in storm events where the presence of calcium chloride minimized initial ice bond formation, but the chemical concentration was not sufficient to prevent icing throughout the storm. Thus, deicing applications comparable to that used on conventionally-treated roadways were required for much of the storm. The net affect was equivalent to that gained by using pretreatment applications, which at the time of this experiment was not an accepted practice. At the time, Vergilimit™ was approximately 1.5 to 3.0 times costlier than regular pavement. Given today's technology and availability of liquid deicers, the use of pretreatment applications is a much more cost-effective practice to achieve the same early storm benefits. In addition, the pavement material was less durable than regular pavement. Thus, MassDOT abandoned any future use of this product.

The results of the PlusRide™ experiment were even less promising as it showed no appreciable benefit for improving roadway conditions or reducing deicing chemical needs. PlusRide™ was designed to be a more flexible pavement than standard bituminous or concrete pavement by inserting rubber particles into the asphalt mix such that the pavement would flex under the weight of vehicles. The flex action would break up a formed pavement-ice bond. The protruding rubber particles in PlusRide™ pavement flex under wheel loads to fracture the ice-pavement bond. PlusRide™ costs almost 50% to 100% more than typical pavement, and is difficult to install. Texas, New York, Minnesota, Washington State, and California all reported durability problems, specifically cracking, chipping and spalling. None of these states found reason to continue to use the PlusRide™ pavement due to its difficulty of handling, cost, and lack of effectiveness.

3.5.1 Open-Graded Friction Course Pavement Layers and Porous Pavement

In the last few years there has been resurgence in the use of Open Graded Friction Course (OGFC) pavement surfaces. MassDOT has installed OGFC surfaces on many of its interstate roadways because it is less noisy, improves pavement friction, and reduces tire spray (increasing visibility during wet weather). The newer generation of OGFC pavement overlays are far superior to the previous OGFC overlays used a decade or two ago because of the newer mixtures of advanced polymer binders, larger aggregates, and fewer fine particles. Previous OGFC pavements were prone to failure in a relatively short amount of time due to raveling and delaminating. The improved design and mix modifications appear to have overcome these deficiencies.

Research at the UNH Stormwater Center has indicated that use of porous asphalt, at least in a parking lot situation, tends to reduce deicer usage because water does not pond at the surface and, thus, there is less opportunity for moisture from rain and snowmelt to freeze on the surface (Roseen et al., 2014). However, whether these same findings can be applied to OGFC pavement is difficult to say as conflicting observations have been reported. In response to a web-based survey, several MassDOT district personnel indicated that OGFC road surfaces tend to cool more quickly due to the open "pores" and, thus, require earlier chemical treatments during snow events to prevent snow from freezing to the pavement. Also, there is a tendency for the applied material to drain down into pavement pores losing some of the deicer effectiveness. On the other hand, less ponding of water during warmer rain and melt events was noted as reducing the need for applications to prevent water from refreezing as compared to dense-mix asphalt. These offsetting aspects of OGFC need to be evaluated further to determine whether OGFC results in less or more deicer usage. Also it is important to note is that the levels of service or standards required to maintain roadways, especially high volume, interstate roadways during winter months are much different than that required for parking lots.

A Clear Roads research consortium is currently sponsoring a pooled-funded research project to evaluate the typical deicer chemical needs on OGFC and full-depth, porous asphalt or concrete and determine whether these more open pore pavement surfaces generally require more or less deicing material compared to dense, non-porous pavement under similar winter weather conditions. The findings of this research are anticipated to be published in the summer of 2017 and will be included in the Final Draft of this ESPR, if available.

4

Roadway Infrastructure and Vehicle Corrosion Damage

4.1 Introduction

Corrosion to infrastructure and motor vehicles is perhaps the most widely known and most costly consequence of deicing material usage. It is not only an issue of cost but of public safety, as the integrity of bridges and other roadway infrastructure can be adversely affected. Although corrosion occurs naturally from exposure to various environmental and climatological elements, deicer chemicals can accelerate or introduce other chemical reactions and/or physical processes that hasten the material degradation process.

This chapter initially describes the potential magnitude of this issue both on a national and state level and the various effects that deicers may have on roadway infrastructure and vehicle corrosion. Vehicle corrosion pertains to both motor vehicles and winter maintenance equipment.

The second part of this chapter describes various BMPs and technological advances used to prevent and/or mitigate the potential corrosion effects from deicing chemical usage. A status update on MassDOT's Accelerated Bridge Program (ABP) to replace or repair structurally-deficient bridges is also provided.

As discussed in Chapter 2, the recent Flint, Michigan water crisis brought to light another corrosion-related concern regarding PWS; the concern that pipe corrosion may lead to changes in water quality. The Flint water crisis was caused by a multitude of factors, not the least of which was the prevalence of old iron and lead-based pipes that connected homes to the main distribution system. The corrosion of these pipes became a serious issue when the City switched to using the Flint River instead of the previous Detroit water source. The Flint River had higher chloride levels, which were eight times higher than those in the Detroit water source as well as other water quality differences such as lower alkalinity and higher dissolved organics, which led to increased leaching of metals in the Flint water system (<http://flintwaterstudy.org/>). Detroit was also adding a corrosion inhibitor (organophosphate) while Flint was not. This chapter briefly describes how increased chloride as well as other related factors may contribute to corrosion in PWS systems based on recent research findings. However, because of the complexity of this issue, it is beyond the scope of this ESPR to describe in depth the wide range of chemical and metallurgy factors involved with corrosion control in PWS systems. Corrosion control measures are regulated under EPA's Lead and Copper Rule.

4.2 Economic Impact of Roadway Infrastructure and Vehicle Corrosion

4.2.1 Economic Impact of Bridge Corrosion on a National Level

The FHWA commissioned one of the more comprehensive studies on the economic impact of corrosion in the United States. The total direct cost of corrosion across five (5) major industries including manufacturing, utilities, transportation, government facilities and infrastructure was estimated to be \$137.9 billion per year. Approximately \$22.6 billion or 16% of these annual costs were related to infrastructure corrosion with approximately \$8.3 billion of these costs related to highway bridges. This includes \$3.8 billion per year needed to replace structurally deficient bridges over the next ten (10) years and another \$4 billion per year estimated to be needed for maintenance and \$0.5 billion for painting and recoating steel bridges. The overall estimate did not include indirect costs to the user due to traffic delays and loss of productivity which was estimated to be ten times greater than the direct cost (Koch et al., 2002). Adjusting for the effects of inflation since 2002, the annual roadway infrastructure corrosion costs increases to approximately \$11.4 billion today assuming an average annual inflation rate of 2.1%.

It is difficult to determine how much of the estimated annual corrosion cost is due to deicing chemical usage versus that caused by naturally-occurring processes. Age is a major factor in assessing the effects of corrosion on our nation's roadway infrastructure. Approximately 53% of the estimated 612,000 roadway bridges in the U.S. are more than 50 years old, according to the National Bridge Inventory Database (last updated in March 2016), which is the average design life for most bridges. Approximately 23% are more than sixty (60) years old. Of the approximately 9.6% or 58,800 bridges that are rated as structurally deficient, nearly three-quarters or 73% of these structural deficient bridges are more than fifty (50) years old (NBI, 2016c). Thus, age and natural corrosion alone are likely to have a predominant influence on the integrity of our nation's bridges.

State transportation agencies are required to perform bridge inspections every two years for all roadway bridges with a minimum length of twenty (20) feet in accordance with FHWA's established guidelines for performing condition assessment and rating criteria. The *FHWA Bridge Inspection Reference Manual*, published in December 2012 and located on the FHWA's website, outlines the federal bridge inspection requirements.

4.2.2 Economic Cost of Motor Vehicle Corrosion on a National Level

The FHWA study also estimated the annual corrosion costs related to motor vehicles to be approximately \$23.4 billion. Much of the estimated motor vehicle costs were attributed to loss of depreciation value (\$14.4 billion), while approximately \$6.5 and \$2.5 billion was estimated to be linked to annual repairs and maintenance and increased manufacturing costs for corrosion resistant materials, respectively. On a per vehicle basis, the annual costs for lost depreciation value, maintenance and repair and increased manufacturing cost were estimated to be approximately \$500, \$150, and \$130 and per vehicle, respectively, for an annual total of \$880, but varied considerably by location (Koch et al., 2002). Adjusting for inflation since 2002, the total estimated annual corrosion cost of \$23.4 billion for motor vehicles would increase to approximately \$32.1 billion today, assuming an average annual inflation rate of 2.1%.

Again, it is difficult to determine how much of the estimated vehicle-related corrosion costs are due to deicer chemical usage versus naturally occurring corrosion. In a previous study, Jones and Jeffrey (1992) suggested that 50% of the estimated vehicle corrosion costs are likely due to deicing material usage. Based on this

estimate, approximately \$11.2 billion of the FHWA's estimated \$23.4 billion in total annual vehicle corrosion costs would be related to deicing chemical usage. In today's dollars, this would be approximately \$16.1 billion by adjusting for the average annual inflation of 2.5% since 2002. However, vehicle manufacturers now utilize more corrosion-resistant materials, which would lower annual depreciation and corrosion related costs. In 2014, the average age of vehicles still on the road was approximately 11.4 years, which is much greater than the average age of seven (7) years in the 1970's for vehicles still in operation (IHS Markit, 2014).

4.3 Corrosive Effects of Deicing Materials on Steel and Concrete

The corrosion of common roadway materials is a complex issue that involves a wide range of both natural and chemical-induced reactions and physical effects. The extent and rate at which corrosion occurs is also influenced by a whole host of design, environmental and maintenance factors. Much of the deicer related corrosion research expressed in the literature focuses primarily on the potential adverse effects to steel and concrete. Although other infrastructure materials can also be affected, this report focuses on providing a brief overview of the corrosive processes and relative differences that the common deicing chemicals may have on steel and concrete. It is important to note that the potential impact deicing chemicals may have on infrastructure is very location specific and to fully assess the corrosion potential due to deicer chemical usage versus natural influences would require a detailed evaluation of a wide array of site-specific factors.

Much of the roadway infrastructure incorporates both steel and concrete components (i.e., reinforced steel concrete), and oftentimes the integrity of one material is dependent of the sustained integrity of the other. The steel embedded in concrete is initially protected by a passive layer of ferrous oxide that forms around the steel within the highly alkaline concrete environment. The cement paste in the concrete matrix is comprised of approximately 50% of calcium-silica-hydrate compounds and approximately 25% of calcium hydroxide (Ca(OH)_2) and has a high bonding strength under a highly alkaline environment with a pH typically around 12.5 (Mahoney et al., 2015).

Over time, chloride-based deicers (e.g. sodium chloride, calcium chloride and magnesium chloride) penetrate the concrete material and replace the hydroxide anions in the calcium hydroxides with chloride anions to form hydrochloric acids, which lowers the pH in the concrete matrix and weakens the bond strength of the cement paste. The weakened concrete matrix is susceptible to the expansive forces as water freezes during freeze-thaw cycles, resulting in more void space and increased porosity allowing for even more chloride and water penetration. The encased steel then becomes more exposed to corrosive reactions associated with oxidation and acidification. Jones and Jeffrey (1992) reported that the corrosion rate of steel is five times greater at pH of 11.5 than at a pH of 12. As the steel rebar corrodes, iron oxides form and expand on the steel surface causing even more cracking in the concrete cover resulting in greater void space, delamination, and spalling of the concrete. Spalling is when large chunks of concrete are displaced due to the pressure by the corroding and expanding surface of the steel which can exert pressures of up 4,000 lb per square inch (Mahoney et al., 2015).

4.3.1 The Effect of Chloride Deicers vs. Non-Chloride Deicers

With respect to concrete corrosion, review of the literature reveals somewhat conflicting evidence as to which of the chloride based-deicers and non-chloride deicers such as CMA tend to cause more damage. Muthumani et al. (2015) reported that calcium chloride and sodium chloride tend to be more corrosive to Portland cement

concrete (PCC) and CMA was the least corrosive. Sumsion et al. (2013), however, reported that magnesium chloride, CMA, and calcium chloride caused the greatest damage to concrete pavement, while sodium chloride caused the least. The study authors suggested that magnesium chloride was more damaging because it had the highest diffusion or penetration rate in concrete materials, followed by calcium chloride and sodium chloride. A Darwin et al. (2008) also reported that magnesium chloride and CMA weakened concrete the most, and sodium chloride had the least corrosive impact. Kahl (2002) reported that CMA caused more damage to concrete because of the chemical reactions associated with magnesium contained in CMA. Shi et al. (2009) also reported that sodium chloride caused less chemical and physical damage compared to magnesium chloride and calcium chloride based on a comparison of concrete cores obtained from existing structures exposed to the various deicing solutions.

For steel corrosion, review of the literature strongly suggests that calcium chloride, especially in liquid form, appears to have the greatest impact and CMA has the least potential impact. Sodium chloride is considered slightly less corrosive than calcium chloride but more corrosive than magnesium chloride on a relative basis. CMA is reported to be far less corrosive than sodium chloride (Kahl, 2002). In the end, selecting a deicer for the purposes of minimizing corrosion could lead to competing interests or tradeoffs in terms of limiting the potential risks between steel and concrete corrosion. For this reason, among others, winter maintenance supervisors are considering deicer blends or hybrid solutions to balance both corrosion protection and anti-icing performance needs. Agricultural byproducts are also used as additives to inhibit corrosion.

As discussed more in Section 4.3, various protective measures are now being used in bridge design and maintenance programs to minimize the amount and rate at which corrosion occurs both for the concrete matrix and the embedded steel. The use of protective coatings and sealants as well as designing structures to divert water away more effectively and limit the accumulation and trapping of water have become common practices. The quality of the concrete material itself in terms of pore structure, type of aggregates used, moisture content, the curing process, and the presence/absence of any micro or macro-cracks can influence the resistance to chloride penetration (Kogler, 2015).

4.4 Recent Advances to Reduce Corrosive Effects of Deicing Materials

4.4.1 Measures to Reduce Corrosion on Roadway Infrastructure

Since 1984, the FHWA has required all bridge replacement or repair projects utilizing federal funds in the snow belt states, to incorporate corrosion protection measures to extend the useful life of bridges. Thus, bridges constructed in the last 30 years or so, are generally considered to be less susceptible to corrosion due to these protective measures.

In December 2015, FHWA released updated design guidelines for corrosion protection for steel bridges entitled "Steel Bridge Design Handbook; Corrosion Protection for Steel Bridges." The FHWA Report (Kogler, 2015) identified the following as typical practices for bridge design and maintenance to prevent or delay the effects of corrosion on bridges:

- Cathodic protection (CP) systems for bridge decks (prevents corrosion in reinforced steel)
- Electrochemical chloride extraction (ECE) treatment (removal of chloride ions around reinforced steel)

- Concrete deck repairs in conjunction with installation of deck overlays, CP systems, or ECE treatment
- Painting/coating or overcoating of structural steel (reduces how fast steel deteriorates)
- ECE treatment for substructure elements
- Substructure concrete repairs in conjunction with installation of CP systems or ECE treatment
- Installation of jackets with CP systems around concrete piles
- Bridge cleaning and/or washing

MassDOT has updated their bridge design manual and standards to include various corrosion protection measures including use of epoxy-coated steel, membranes, sealants, weathered steel and applying metal coatings through galvanizing and/or metalizing the steel components. Metalizing and galvanizing provides more effective, long-term protection for steel than regular coatings. Metalizing refers to the process of thermally applying a sacrificial metal coating onto the steel surface. This is done by using a heat source to "melt" metal over the target steel surface and allowing it to solidify. This can be done in place or at the manufacturing facility. This process is more labor-intensive than painting or applying other coatings, but provides a more durable coating and requires no solvents or airborne related pollutants.

Galvanizing refers to applying a continuous layer or coating of zinc over steel. The mode of application can utilize various methods including mechanically-deposited galvanizing, continuous sheet galvanizing and hot-dip galvanizing. Galvanizing is primarily done as part of the manufacturing process and for bridge components it is typically done using the mechanical or hot-dip application methods as the continuous sheet method is used for flat, steel sheets like highway signs.

MassDOT also utilizes sealants and additives in the concrete mixtures which can slow the rate of corrosion by reducing the rate of intrusion of chloride anions into the concrete or mortar. Common sealants such as siloxane and silane typically last three to five years and need to be reapplied periodically

Certain additives or use of alternative materials in the concrete mix such as fly ash and silica fume have been shown to reduce the permeability of concrete. MassDOT has been specifying the use of silica fume for new concrete structures in certain locations that may be more prone to corrosion. Reducing the water to concrete ratio has also been shown to increase strength although there have been some conflicting results. One study found that using a high-quality concrete mix with a water to cement ratio of less than 0:40 was ideal for lowering chemical penetration (NCHRP, 2007), while other studies suggest that lowering water to cement ratios has had limited effects. Other mitigation strategies include use of more durable aggregates that are less susceptible to freeze-thaw cycles, or establishing tighter controls on the air-void system (concrete with 5-7% entrained air) that reduce the potential for shrinkage cracks and surficial defects during the curing process.

MassDOT also maintains a bridge washing program using water from local sources to rinse any residual deicing material and sand from bridge decks and the underlying support structure. The washing is done without the use of detergents. The washing is generally done using high-pressure systems with fine mist nozzles to limit water use and generation of runoff.

4.4.2 Status of Massachusetts Accelerated Bridge Program (APB)

In 2008, the MassDOT launched the APB to quicken the process of repairing and reconstructing structurally-deficient bridges located throughout the state. At the time, approximately 10% of the total 5,167 bridges located in the State of Massachusetts were considered structurally-deficient. As of October 1, 2016, the

number of structurally-deficient bridges in the state has dropped to 432, representing a 20% drop in the number of structurally-deficient bridges (MassDOT, 2016a). The number of structurally-deficient bridges represents about 8.4% of the total number of bridges in the state. Just over 90% of the structurally-deficient bridges are over 50 years old based on 2015 NBI data (NBI, 2016c).

Table 4.1 summarizes the estimated number of bridges in Massachusetts within various age categories and percentage of these bridges that are deemed structurally deficient within each age category. MassDOT is responsible for inspecting the condition of all bridges in the state, even though approximately 1,500 bridges are municipally owned. To maintain regular inspections, MassDOT currently has 39 bridge inspection teams throughout its six maintenance districts, including four underwater "dive" teams. Through a combination of in-house teams and hired consultants approximately 2,400 bridge inspections are performed each year. The *MassDOT Bridge Inspection Handbook; 2015 Edition* provides inspection guidelines on condition assessment criteria, inspection methods, inspection waivers, and qualifications for bridge inspectors.

Table 4.1: Summary of Structurally Deficient Bridges by Year Built and Age in Massachusetts

Year Built	Age	Total #	Total # Structurally Deficient	% Structurally Deficient
1991-2015	0-25	909	2	0%
1971-1990	26-50	945	40	9%
1941-1970	51-75	1,997	197	43%
1916-1940	76-100	782	149	32%
1915 and earlier	>100	533	73	10%
TOTAL		5,167	461	8.9%

Source: National Bridge Inventory (NBI) database last updated in March 2016; NBI, 2016b.

Table 4.2 summarizes the total number and structurally deficient bridges within the state by primary construction material type including conventional reinforced concrete, pre-stressed concrete, steel, wood, masonry, and aluminum iron. Approximately 58% of the state's bridges are constructed primarily with steel components and the second-highest category consisting of pre-stressed concrete, which comprise another 21% of the total. More importantly, bridges comprised mainly of steel represent 75% of the structurally deficient rated bridges.

Table 4.2: Summary of Structurally-Deficient Bridges By Construction Material Type

Constructed Material Type	Total Number of Bridges	Structurally Deficient Bridges	Percent Deficient
Conventional Reinforced Concrete	850	52	6.1%
Pre-stressed Concrete	1,097	33	3.0%
Steel	2,991	345	11.5%
Wood	59	8	13.6%
Masonry	143	19	13.3%
Aluminum Iron	20	3	15.0%
Other	7	1	14.3%
Total	5,167	461	8.9%

Source: NBI database last updated in March 2016; NBI, 2016b

Since the early to mid-1980's, MassDOT has progressively adopted a variety of corrosion prevention measures in its bridge design requirements and maintenance operations, while particularly focusing on bridges comprised of steel components. These measures, described in more detail in Section 4.2, have reduced the

corrosion rate and prolonged the design life for steel bridges. However, given the predominance of older bridges (i.e., pre-1980's) still in use, steel bridges are likely to make up a high percentage of structural-deficient rated bridges until the repair/replacement backlog of older steel bridges has mostly been completed.

4.4.3 Measures to Reduce Corrosion in Vehicles

Vehicle manufacturers have made significant progress over the last 20 to 30 years in making vehicles more corrosion resilient by changing the materials used in their design. Vehicles today are made of a variety of corrosion resistant metal alloys, plastics and resin composites and much less steel. Where metal is still used, manufacturers have incorporated different coatings, splash guards and improved drainage to limit exposure to trapped water. Because of these advancements, it is not uncommon for vehicles to be driven well beyond 10 years and even 20 years or more, back in the 1970 and 1980's, when vehicles rarely lasted beyond 10 years due to corrosion issues. For the most part, vehicle corrosion and related maintenance needs have become less of an issue given the various manufacturing improvements. The benefits of extended vehicle life and reduced corrosion related maintenance costs are likely to far outweigh the added manufacturing costs. As new materials and design modifications continue to advance in the future, vehicles should continue to become more corrosion resistant.

Certain vehicle components are more vulnerable to corrosion than others such as fuel line, brake pads and rotors, and exhaust and electrical systems primarily because of their metal alloy composition and exposure to road spray and splashing beneath the vehicle. Exhaust systems traditionally were one of the most vulnerable and most expensive vehicle components to replace, but most are now made with rust resistant metal alloys and even stainless steel to provide greater longevity. Wheel rims are also now mostly made with aluminum alloys which are more corrosion resistant than steel rims. Periodic vehicle washing during winter months using commercial car wash facilities with under-carriage high pressure nozzles is generally recommended by most vehicle manufacturers (NCHRP, 2007).

4.4.4 Measures to Reduce Corrosion on DOT Equipment

Vehicles and equipment used by transportation agencies for snow and ice control are used in the harshest of conditions and are often directly exposed to deicing materials for prolonged periods. Thus, this equipment is most susceptible to the potential corrosive effects. A state-by-state survey of transportation agencies within the U.S. revealed that fleet equipment corrosion represents an average annual cost of approximately \$14 million per state with depreciation, premature repair and replacement, and reduced service life as three of the largest cost factors (Shi et al., 2013). MassDOT spends approximately \$2.5 to \$3 million per year in equipment repairs as part of its SICP although all the repairs are not necessarily due to corrosion.

Minimizing equipment corrosion through preventative and maintenance measures can lead to significant cost savings associated with depreciation and replacement costs by extending the service life. The *Manual of Best Practices for the Prevention of Corrosion on Vehicles and Equipment used by Transportation Agencies for Snow and Ice Control* (2015) by Clear Roads provides detailed recommendations for managing DOT equipment and vehicles to prevent or reduce the impact of corrosion. The primary recommendations for corrosion management include: (1) use of stainless steel components as much as possible; (2) washing equipment and vehicles regularly; and (3) use of corrosion inhibitors either contained within the deicing chemical or occasionally sprayed directly on the equipment itself several times throughout the year (Nazari et al., 2015).

MassDOT has recently begun using a liquid magnesium chloride product (ProMelt) that contains a small amount of biodegradable corrosion inhibitor to minimize equipment and infrastructure corrosion. The corrosion inhibitor is a proprietary organic substance and comprises less than 1% of the liquid MgCl₂ deicer product by volume (MassDOT, 2016b). Information on the effectiveness of these inhibitors on reducing corrosion appears to be limited and are still being investigated (Muthamani et al., 2015).

MassDOT also maintains a Vehicle Washing Program to maintain and prolong the life of its equipment fleet. Washing of MassDOT vehicles during winter months is done indoors at appropriate facilities and in accordance with MassDOT's Environmental Handbook. The Handbook describes appropriate vehicle washing facilities as being those that are either connected to a municipal sanitary sewer system or a subsurface holding tank.

The recent Clear Roads BMP Manual also recommends that maintenance programs include additional staff training to identify and implement other preventative maintenance measures of DOT equipment as well as improved monitoring and inspections, which could lead to additional financial savings (Nazari et al., 2015).

4.5 Corrosion Control in PWS Infrastructure

EPA (2016) recently published guidance on optimal treatment controls, disinfection and coagulation processes to minimize the corrosiveness of water with metal surfaces in the water distribution system. This report was released following the recent Flint Michigan water crises, which certainly raised awareness on the importance of water quality monitoring in drinking water supplies and how changes in water quality can affect potential corrosion and leaching of metals in water supplies. In 1991, the U.S. EPA adopted the Lead and Copper Rule, which requires PWS to control the release of lead and copper in water distribution systems by managing the various water quality and physical interactions that can affect metal releases. It is beyond the scope of this ESPR to fully describe the complex monitoring and treatment activities involved with complying with this regulation. Adequate corrosion control depends on a wide array of water quality interactions and physical characteristics related to PWS systems to ensure safe drinking water to consumers.

Internal corrosion depends on a wide variety of interactions with various water quality parameters including pH, alkalinity, specific conductance, total DIC, hardness, chloride, sulfate, TDS, dissolved oxygen and oxidation-reduction potential. Changes in water quality within an existing water source, water source(s), or chemicals used in treatment processes, such as for coagulation or hardness, can change the risk potential for internal corrosion. The quality and type of metals inherent to the plumbing systems are also critical factors.

With respect to chloride, research has shown that when the CSMR exceeds a threshold of 0.7, this may lead to more galvanic corrosion with lead solder used on copper pipes in plumbing fixtures (Edwards and Triantafyllidou, 2007). A higher CSMR can result if coagulants used in the treatment process are changed from a sulfate-based type (e.g., aluminum sulfate or ferric sulfate) to a chloride based coagulant such as ferric chloride. Use of other chemicals for anion exchange for treatment of hardness or arsenic can also contribute to a higher CSMR. Chlorides increases in in the source water due to the use of deicing salts or salt water intrusion along the coastline can also contribute to a higher CSMR.

Nguyen et al. (2011) reviewed nine (9) case studies in PWS systems in North America where the presence of lead was more frequently detected in the water distribution system following a change in either the treatment

process or source of water that resulted in a higher CSMR. The increased CSMR in most of these cases was attributable to a change in treatment chemicals. In one case, the higher CSMR was caused by a chloride leak into the system from a hypochlorite system used to disinfect the finished water. In review of these cases, researchers found that other water quality parameters had a contributing role in the increased lead leachability beyond the higher CSMR. Specifically, lower pH values and low alkalinity were common contributing factors. Raising the pH and/or buffer capacity brought the lead levels and detection frequency to where they were before the change occurred, even though the higher CSMR remained. In some cases, appropriate corrosion inhibitors were used to mitigate any increased corrosion in the water supply system.

The findings of this research indicate that chloride can be a contributing factor to increased internal corrosion in PWS systems, but, its influence depends mainly on other water quality interactions and especially the presence of sulfate ions. In other words, elevated chloride levels in source waters by itself is not a definitive indicator of increased corrosiveness and greater releases of metals. A comprehensive evaluation of other water quality parameters is required to fully assess the internal corrosion potential.

It is difficult to estimate the potential magnitude of this problem statewide, or more specifically, the number of PWS systems that have a CSMR above the suggested threshold of 0:7. Since chloride has a SMCL of 250 mg/L for aesthetic reasons, most (if not all) PWS are likely to be monitoring chloride levels. However, it would require an extensive effort beyond the scope of this ESPR to compile and evaluate the necessary water quality data, including sulfate levels, in the various PWS systems throughout the state to be able to assess the potential magnitude of this corrosion issue statewide.

The Effect of Winter Weather on Public Safety and Vehicle Mobility

5.1 Introduction

This chapter provides a general summary of the impact that winter weather can have on public safety (i.e., vehicle crashes) and economic activity through reduced vehicle mobility based on data reported at the national and state level. Slick roads and poor visibility during winter weather have been shown to adversely affect vehicle crash rates and vehicle mobility, which not only impacts individual drivers, but the regional economy as well due to increased property damage costs, emergency response service costs, lost workplace productivity, medical costs and other congestion-related costs. Increased travel times due to decreased vehicle mobility can result in delayed shipping, reduced business and tourism activity, as well as increase fuel consumption and vehicle emissions which can also lead to economic impacts. Improving road conditions through winter road maintenance activity to mitigate these impacts is a principal driver of the SICP.

The potential benefits of winter maintenance activities must also be weighed against the potential impacts on infrastructure and environmental resources as discussed earlier in previous chapters due to deicing chemical usage and/or use of sand for traction purposes. These impacts also result in socio-economic costs as they relate to either increased corrosion, as discussed in Chapter 4, or lost or diminished ecosystem services provided by roadside soils, vegetated areas and water bodies. Key ecosystem services that may be affected using deicing chemicals and sand include drinking water quality, wildlife habitat, water and nutrient retention and biomass production, among others.

5.2 The Effect of Winter Weather on Vehicle Crash Rates

Approximately 70% of the nation's roadways are in regions that receive at least 5 inches of snow on average each year (FHWA, 2016c). Reduced visibility due to precipitation and wind-blown snow and reduced pavement friction are the two most critical winter-weather related factors that impact vehicle crash rates.

The following provides a review of vehicle accident data during winter weather on a national and state level. In general, drivers have greater difficulty adjusting to winter weather early in the season. Pisano et al. (2008) found more accidents related to winter storm events occur at the beginning of the season due to the delayed adjustment to weather conditions.

5.2.1 The Effects of Winter Weather on Vehicle Crashes on a National Level

Based on annual vehicle crash data reported between 2005 and 2014, the FHWA reports that, on average, approximately 1.3 million vehicle crashes in the U.S. or 22% of the total number of crashes each year were weather-related. Of these weather-related crashes, on average, over 445,000 crashes resulted in injuries and nearly 6,000 crashes resulted in fatalities each year. Approximately 73% of these weather-related crashes occurred on wet pavement conditions and another 24% occurred on snowy, slushy, or icy pavement. Overall, approximately 15% of weather-related accidents occurred during actual snowfall or sleet storm events (Booz Allen Hamilton, FHWA, 2016b). Even though more weather-related accidents occurred on rainy days, the daily accident rate has generally been found to be much higher on snow days than on rain or clear weather days. A comparison of accident rates during winter months and non-winter months in Massachusetts is presented in Section 5.1.2 below using historical reported crash data information.

Winter-related accidents do, however, generally result in fewer fatalities. Eisenberg and Warner (2005) and Rubin et al. (2010) both reported fewer fatalities during winter storm events. Tefft (2016) also found that crashes that occurred during snow or sleet had a lower fatality rate than those occurring during rain and clear weather. The fewer fatalities is presumably due to slower vehicle speeds during winter storm events resulting in less severe crashes despite a higher incidence of accidents.

Studies have found that better road conditions resulting from winter maintenance activities can reduce the number of winter-weather related crashes. Fu and Usman (2012) estimated that winter maintenance activities in Ontario reduced the number of vehicle collisions by 26% to 42% depending on roadway type and traffic volumes. Other influencing factors include temperatures, storm intensity, duration, and time of day. Fay et al. (2015) reported that use of road salt reduced vehicle crashes by approximately 51% while the combination of plowing and salting resulted in a 65% reduction in vehicle crashes. Ye et al. (2013) estimated that winter road maintenance in Minnesota reduced the statewide vehicle accident rates by approximately 29%, a difference of 4,600 crashes. Similar to other studies, this study found that the effects of winter road maintenance on vehicle accidents depended on various weather and road related factors including storm severity, roadway type, traffic volumes, time of day, type and frequency of maintenance activity, as well as other factors.

In addition to fewer vehicle accidents, winter road maintenance can result in other economic benefits related to increased vehicle mobility such as reduced fuel consumption, enabling commuters to travel to work, and minimizing disruptions to freight traffic as well as retail and other business activity. For example, Ye et al. (2013) estimated that the reduction in vehicle accidents due to winter road maintenance activities in the State of Minnesota resulted in approximately \$227 million in social economic benefits each winter season. Approximately 75% of the estimated benefits relates to the avoided costs associated with the estimated 29% fewer vehicle accidents linked to winter road maintenance. The remaining benefits relate to estimated travel time savings and fuel consumptions savings. The potential impact of winter maintenance practices on economic activity is further discussed below in Section 5.3.

An earlier study conducted by Marquette University reported that every \$1.00 spent on direct roadway maintenance activities resulted in approximately \$6.50 in direct benefits in avoided cost with fewer vehicle accidents. The avoided costs relate to property damages, medical expenses, emergency services, workplace costs, travel delays, legal and other administrative expenses that were avoided by 88% fewer accidents after deicing materials were applied on a two-lane roadway (Hanbali and Kuemmel, 1992).

5.2.2 Effect of Winter Weather on Vehicle Crash Rates in Massachusetts

Massachusetts has a centralized vehicle crash records system referred to as the Crash Data System (CDS) database that is managed by the RMV Division within MassDOT. Vehicle accident reports are submitted by state or local law enforcement agencies both in electronic and paper form. Approximately 60% of the crash reports are received electronically and the remaining 40% of reports are received in paper form (Benac et al., 2014). State regulations require law enforcement agencies to submit reports to the RMV for any accident that involves an injury or fatality or property damage in excess of \$1,000. The report form allows the preparer to note the road surface and weather conditions that were occurring at the time of accident. MassDOT is responsible for processing, formatting, and geocoding the location of the accident (if not currently recorded) and making it available to the public upon request. The crash report form was most recently updated in 2013 and includes the following report fields, which are inputted into the CDS.

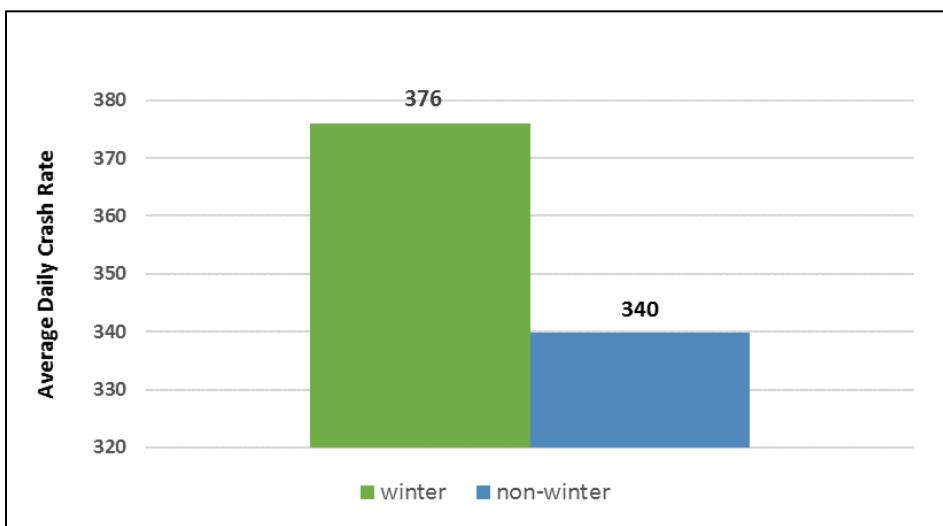
Crash Data System Data Fields

- Crash number
- City/town name
- Crash date and time
- Crash severity
- Number of vehicles
- Total nonfatal injuries
- Total fatal injuries
- Manner of collision
- Vehicle action prior to crash
- Vehicle travel direction
- Most harmful events
- Vehicle configuration
- Road surface condition and weather condition
- Distance from nearest roadway intersection
- Distance from nearest mile marker or from nearest exit
- Non-motorist type
- Lat. and Long. Coordinates

Although the RMV continues to simplify the reporting and submittal process for the vehicle CDS, there is still considerable variability in the data consistency, accuracy and completeness both historically and on a case by case basis. In the early years of the CDS system, the report length and time required to complete accident forms discouraged people from reporting. However, with updates to the report form and with electronic reporting made available, the percentage of accidents reported as well as the data accuracy and completeness of the reports has steadily improved in recent years. Data accuracy and completeness, with respect to more ancillary factors such as weather and road conditions, may depend on the time of day, location, severity, availability of time of local or state police and other safety concerns associated with the accident. Property-damage only (PDO) crashes are generally recognized as being under-reported, especially relatively minor PDO crashes, which generally represent a high percentage of winter-related crashes. In fact, an analysis of the Massachusetts Vehicle Crash Data revealed that approximately 30% of the PDO crashes in the state go unreported and at times the percentage could be higher during adverse weather and may depend on other factors such as time of day, location and any safety issues associated with each crash (Benac et al., 2014).

Figure 5.1 compares the average daily vehicle crash rate reported during winter months (November-March) versus those reported in non-winter months (April-October) for the period of 2006 to 2014. The data indicates that, on average, there are approximately 376 vehicle crashes for each winter day compared to an average of 340 vehicle crashes per non-winter day indicating an average increase of 36 vehicle crashes on winter days. This increase in the average daily crash rate suggests that there are more than 1,000 additional crashes each winter month and approximately 5,400 additional vehicle crashes (36 crashes x 151 days) over the course of the winter season (November-March). Presumably, the additional crashes are due to adverse road and weather conditions during the winter period. It is important to note that many of the winter weather vehicle crashes are likely to go unreported compared to non-winter crashes since there is a higher percentage of PDO crashes, as discussed above. Thus, with a more accurate estimate of PDO crashes, the difference in average daily crash rates between winter and non-winter months could potentially be much greater.

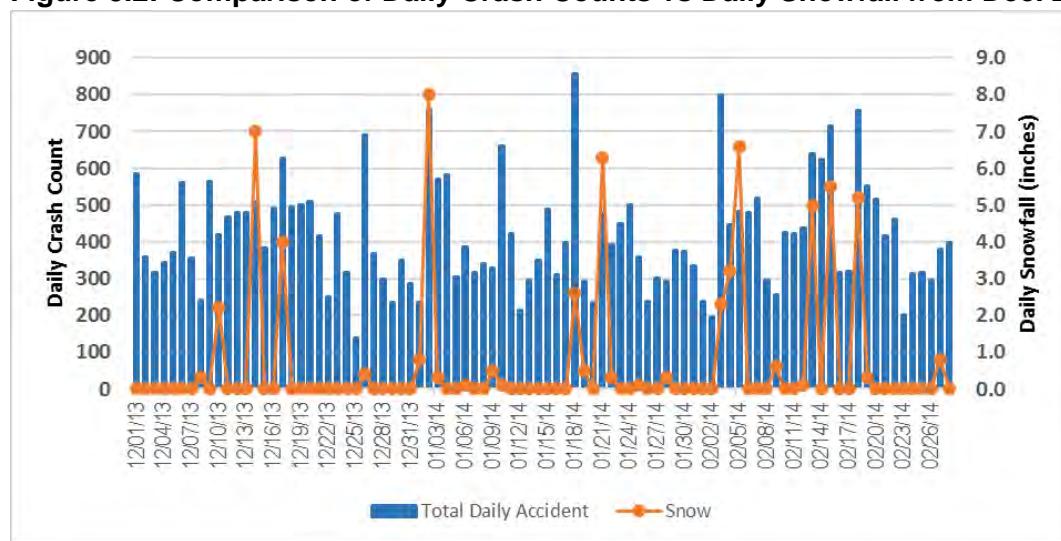
Figure 5.1: Comparison of Average Daily Crash Rates for Winter and Non-Winter Periods



Source: Mass Crash Data System for Years 2006-2014: Winter Months include November through March

Figure 5.2 compares the statewide daily vehicle crash totals with daily snowfall totals from December 2013 through February 2014 (latest data available). This comparison generally shows that daily crash counts tend to be higher on days with measurable snow, although the impact of snow is widely variable and some of the highest daily crash counts are not necessarily on days with the greatest snowfall. For instance, January 18th and February 3rd of 2014 had the highest daily crash counts (i.e., approx. 800 crashes or more), but had less than 3.0 inches of snow, whereas December 14th, January 2nd, January 21st and February 5th had more than 6.0 inches of snow, but much lower crash totals. Other weather-related factors such as visibility, precipitation intensity, and temperatures are likely to affect the daily crash totals as well. The impact of snowfall on daily crash totals is likely to depend on storm timing relative to peak traffic periods as influenced by the time of day, day of the week, and holiday period vs. non-holiday periods, etc. Traffic volumes may also tend to be lower on days when larger snowfall totals are forecasted as commuters opt to stay home and schools are closed.

On average, there were approximately 417 reported crashes per day during this December 1st to February 28th period (90 days) or approximately 11% higher than the 10-year average winter crash rate discussed above. There were 27 days with measurable snow but there were 36 days with more than 500 reported crashes. Thus, other factors are likely to contribute to daily winter accident rates, aside from measurable snowfall, such as blowing snow, freezing rain, fog and slippery road conditions due to freezing of moisture from melting.

Figure 5.2: Comparison of Daily Crash Counts vs Daily Snowfall from Dec. 2013 to Feb. 2014

Source: Mass Crash Data System

5.2.3 Recent Vehicle Crash Rates Following Use of Anti-icing and Equipment Upgrades

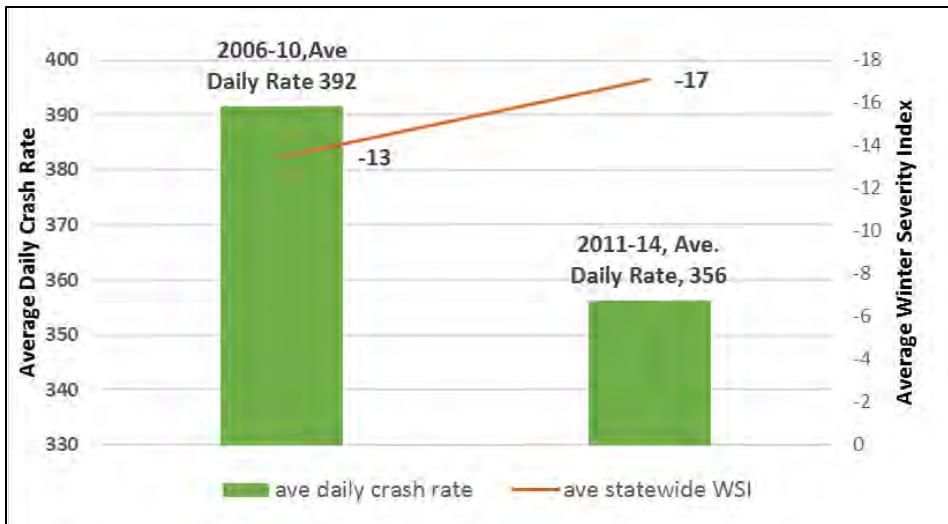
As mentioned earlier, improving road conditions through plowing and deicing applications can reduce the adverse effect that winter weather can have on vehicle crash rates, particularly when using anti-icing techniques to prevent snow and ice from bonding to the pavement.

Figure 5.3 shows that the average winter daily crash rate for the last four (4) years (2011-14) following the adoption of anti-icing techniques and other equipment upgrades compared to the average winter daily crash rate in the previous 5 years (2006-10). Approximately 9% fewer crashes occurred during the 2011-14 period even though the average WSI (WSI = -17) indicated more severe winter weather as compared to the previous 2006-10 period (WSI = -13). Annual traffic volumes as expressed in total vehicle miles traveled (VMT) were also higher in 2014 at 57 million VMT compared to approximately 54 million VMT in 2006 (FHWA Statistics, 2016). The lower average winter daily crash rate suggests that, on average, there were approximately 5,400 fewer crashes during the winter period (November-March) in the last four (4) years. This reduction in crashes is likely due in large part to better road conditions resulting from MassDOT's use of anti-icing practices that began in the winter of 2011, particularly given that the more recent winters were generally more severe. Other factors may have also contributed to lower accident rate, such as enhanced weather forecasting and use of early warning systems, newer safety features in late model vehicles and perhaps a higher percentage of commuters being able to work from home during adverse weather. As more recent vehicle crash data becomes available, it will be important to confirm whether this trend in lower daily crash rate continues because fewer vehicle crashes can result in substantial socio-economic benefits as discussed below.

It is also important to note that the non-winter daily crash rate (April-October) was also lower during the period of 2011 to 2014 compared to 2006 to 2010, but not to the same extent as the winter month daily crash rate. The average daily non-winter crash rate in the 2011-14 period was approximately 5.5% lower than that reported for the 2006-10 period during non-winter months. Perhaps other factors such as better weather forecasting, enhanced driver warning systems, advanced vehicle designs and braking systems, reduced speeds, and driver behavior may have also contributed to lower crash rates in recent years compared to previous years.

The difference in the more recent winter average daily crash rate compared to that in the previous five (5) years is essentially the same (i.e., 36 fewer crashes per day) as the estimated difference between the average winter and non-winter average daily crash rate, discussed in Section 5.1.2 above. The fact that the results of these two comparisons are the same is considered purely a coincidence since the data used in these two comparisons are completely different.

Figure 5.3: Average Daily Crash Rate During Winter Months Between 2006-10 and 2011-14 Periods



5.3 Estimated Costs Associated with Vehicle Accidents

This section provides a general assessment of the potential economic costs associated with winter related vehicle crashes based on reported vehicle crash data and related cost information expressed in the literature at the national and state level. A similar assessment of the potential cost savings resulting from fewer winter vehicle crashes as a result of enhanced winter road maintenance practices is also provided.

5.3.1 Estimated Costs Associated with Vehicle Accident Rates Nationwide

Blincoe et al. (2015) estimated that the economic cost associated with the 5,419,000 motor vehicle crashes that occurred in 2010 in the U.S. was approximately \$242 billion in 2010 dollars. These economic costs include lost workplace productivity, property damage, medical treatment, legal and court fees, emergency service costs, insurance administration costs, wage losses and other congestion related costs. These estimated costs translate to an average cost per crash of approximately \$44,658 and an estimated per capita cost of approximately \$784 for United States.¹ Table 5.1 presents a breakdown of the estimated annual costs on a national basis for each of the major Loss categories associated with vehicle crashes based on national statistics.

¹ The authors of the study noted that the U.S. population in 2010 was 308.7 million people.

Table 5.1: National Annual Cost Estimates for Major Loss Categories Associated with Vehicle Accidents

Loss Category	Estimated Annual Costs	Percentage of Total Economic Costs
Lost Workplace Productivity	\$57.6 billion	24 %
Total Property Damage	\$76.1 billion	31 %
Present and Future Medical Costs	\$23.4 billion	10 %
Congestion Costs	\$28 billion	12 %
Lost Household Productivity*	\$19.7 billion	8 %
Insurance Administration	\$20.6 billion	9 %
Legal and Court Costs	\$10.9 billion	4.5 %

*Lost Household Productivity includes costs of hiring help to perform household tasks (e.g. cooking, cleaning, yard work) due to personal injury and temporary or permanent disabilities.

Source: Blincoe et al., 2015.

Total property damage and lost workplace productivity account for 55% of the estimated vehicle crash-related costs. Medical costs account for another 10% of the estimated annual crash-related costs. As discussed earlier, a large portion of the overall vehicle crash related-costs are associated with fatalities and serious injuries. The authors of the study note that the average lifetime economic cost to society for each fatality is estimated to be approximately \$1.4 million, of which there were 32,999 reported vehicle related fatalities in 2010. Congestion costs account for 12% of the estimated annual costs and include direct and indirect costs associated with travel delays, such as increased fuel consumption, lost productivity, and adverse environmental impacts due to added vehicle emissions. The study noted that approximately 75% of the estimated annual vehicle crash-related costs or approximately \$187 billion are borne by society or those not directly involved in the crash through insurance premiums, taxes used to support public services, and congestion related costs (Blincoe et al., 2015).

The Blincoe et al. (2015) study also reported that most winter weather related accidents are comprised of PDO crashes with fewer fatalities and serious injuries, presumably due to lower vehicle speeds during the inclement weather. The study reported that the average cost per damaged vehicle in PDO crashes was approximately \$3,860 in 2010 dollars. The study also noted that approximately 60% of the PDO crashes and 24% of all injury crashes are not reported to the police (Blincoe et al., 2015). As noted earlier, a recent analysis of the Massachusetts Vehicle Crash Data revealed that approximately 30% of the PDO crashes in the state go unreported and the percentage is likely to vary depending on weather, location, time of day and other safety related factors associated with each crash (Benac et al., 2015).

5.3.2 Estimated Winter Weather Related Vehicle Crash Costs in Massachusetts

As discussed in Section 5.1.2, the vehicle crash data for the period of 2006 to 2014 suggests that, on average, there are approximately 5,400 additional vehicle crashes during the winter period (November-March) as compared to a similar 5-month period from April to October. These additional crashes are most likely due to poor visibility and road conditions during winter weather events. On an annual basis, the difference in the number of winter and non-winter vehicle crashes will depend on the winter weather severity as well as other road related factors.

Using the estimated cost data reported by Blincoe et al. (2015), the added costs associated with the additional winter related vehicle crashes in Massachusetts can be estimated. Of the 189,048 vehicle crashes reported in

Massachusetts in 2010 (latest totals available), the total estimated cost was approximately \$5.8 billion. This translates to an average cost of approximately \$33,325 per crash in 2010 dollars. Based on this average crash cost data the additional costs of the 5,400 additional vehicle crashes estimated to occur in the winter period would be approximately \$180 million per year. This cost estimate may be at the high end since average cost for winter related crashes is likely to be lower given that winter crashes tend to be less severe and most may only be PDO crashes. Blincoe et al. (2015), reported that the average cost per PDO crash was approximately \$3,825 per vehicle. Insufficient data exists to adequately estimate the number of winter weather crashes that are PDO crashes only versus other types of crashes. The potential cost per vehicle crash varies widely and depends mostly on crash severity with the highest costs generally linked to crashes involving fatalities and lowest costs associated with PDO crashes.

Using the same vehicle crash cost data, described above, the potential economic benefits (i.e., cost savings) gained by fewer winter related crashes as indicated by the Massachusetts vehicle crash data can be estimated. The crash data suggests that the average winter daily crash rate has declined by approximately 9% (i.e., 36 fewer vehicle crashes per day) in the last four years (2011-14) compared to the previous five years (2006-11) despite the average WSI value suggesting that the last four years had more severe winter conditions. Given that MassDOT maintains the largest roadways in the state which convey the bulk of the average daily traffic volume, it seems reasonable to assume that the recent lower daily crash rate could be due to MassDOT's use of anti-icing practices as well as other equipment upgrades and technologies since 2011, particularly since traffic volumes and winter weather conditions have remained the same if not worsened over the same period. Other factors may have also played in role in the reduction in winter vehicle crash rates but to a lesser degree.

The lower average daily crash rate suggests that approximately 5,400 fewer winter-weather related crashes have occurred in Massachusetts, on average, in the last 4 years. Using the average per crash cost of \$33,325 and the same assumptions, discussed above, the estimated cost savings associated with approximately 5,400 fewer winter related crashes could be as much as \$180 million per year. Again, given that winter related crashes tend to be less severe and result in more PDO crashes, the average cost per crash is likely to be lower than that for non-winter crashes. On the other hand, many of the PDO crashes tend to go unreported and, thus there could be an even fewer winter related crashes due to improved road conditions. It is also important to note that the cost data related to vehicle crashes as reported in the FHWA study Blincoe et al., (2015) are based on 2010 dollars.

A more detailed analysis of the contributing factors that may affect vehicle crash rates including roadway type, weather, road conditions, crash severity, number of vehicles involved, related injuries, etc., would be required to develop a more informed estimate of the potential savings or economic benefit that may result from fewer winter related vehicle crashes. This data is not consistently available and has various limitations, but this is an area that MassDOT is working to improve and track more closely in the future.

5.4 Economic Impacts of Reduced Vehicle Mobility During Winter Weather

Major winter storms can wreak havoc on transportation systems and inflict serious economic impacts due to loss of retail sales, income, and sales tax revenues. Winter weather has been reported to be the second leading cause of non-recurring highway congestion, accounting for approximately 15% of traffic delays nationwide (Rall, 2010). Improving roadway conditions through winter road maintenance activity can have a substantial bearing on vehicle mobility and economic activity.

5.4.1 Economic Impact of Winter Weather and Reduced Vehicle Mobility in Massachusetts

The MEMA estimated that the extreme winter weather of 2015 resulted in approximately \$393 million in additional state program costs just in snow removal, property damage, and public assistance. Most of these costs were due to a series of storms that occurred over a three-week period from January 26, 2015 to February 22, 2015 (MEMA, 2015). During this time, a total of 171 lane or road closures were reported with some roads closed for significant durations. An official travel ban was established for nearly a 48-hour period. The following summarizes just a few of the reported economic impacts caused by this extreme winter period:

- Cities and towns spent approximately 1.4 times more on winter maintenance than was budgeted.
- Total snow removal and roadway maintenance costs for MassDOT were \$89,382,459.
- Estimated loss in revenue at Boston area hospitals was \$10,384,000.
- Estimated cost of repairs (road systems, bridges, water control facilities, buildings, equipment, utilities, parks, recreation, etc.) was \$28,723,779.
- Total estimated loss in toll revenue for MassDOT was \$2,681,872.

Other state agencies such as the MBTA, MassPort, and the Steamship Authority also reported significant losses of approximately \$22.4 million, \$13.3 million and \$0.4 million, respectively, due to reduced operations and cancelled trips. Retail sales were estimated to decline by 22% and employee payroll dropped by approximately 7% (MEMA, 2015). The economic impacts extend well beyond the Boston metro area with many businesses, institutions and industries having to curtail operations either due to reduced travel mobility or added snow removal costs. The delivery and production of goods are also adversely affected. The impact to agricultural crop production due to actual crop damage or due to extended snow cover can be significant.

A previous study conducted by IHS Global Insight (2010) estimated that a one-day shutdown in Massachusetts could result in an economic impact of \$265.1 million. Much of the impact was attributed to lost wages for hourly workers (\$194 million), but also included estimated losses in retail sales (\$40.5 million), and lost federal, state, and local tax revenue (\$30.5 million). These cost estimates assume that all businesses and government agencies would be closed due to impassable roads and the closure of other modes of transit. Although this represents a worst-case scenario, it is similar to what occurred in a major blizzard of February 2015 when much of the MBTA rail system was shut down for at least a day. Despite the MBTA shutdown, a certain number of employees were still able to get to work and increasingly more people are able to work from home. However, even if the IHS estimated economic impact of a one-day shutdown was reduced by 25% or 50% to reflect that some employees are still able to work and some level of retail activity is still likely to occur, the adjusted cost estimates of approximately \$130 to \$200 million still represent a relatively large economic impact for a one-day snow event.

Shipping and trucking is a transportation industry that is particularly affected by adverse road conditions and winter weather. Rall (2010) reported that winter weather is the second leading cause of non-recurring highway congestion and accounts for approximately 15% of traffic delays nationwide. In 2016, the FHWA estimated that approximately 544 million vehicle-hours per year are lost due to adverse weather traffic delays (includes snow, ice, or fog). FHWA estimated that the annual cost to trucking company's due to weather-related delays ranges from \$2.2 to \$3.5 billion per year. (FHWA, 2016b).

Relative to the impact of traffic congestion alone, a Texas Transportation Institute study estimated that traffic congestion delays in the Boston-area cost the average commuter in additional 64 hours in commuting time during 2014 (latest data available). This ranked as the sixth highest traffic delay time for peak commuting hours amongst 471 urban areas nationwide. The estimated added cost to each commuter associated with these delays was \$1,388 per year based on an assumed hourly value of \$17.67 per person and \$94.04 per hour for trucks as well as increased fuel consumption costs (Schrank et al., 2015). Not all the annual traffic delay time can be attributed to winter weather, but even if 15% of the traffic delay time is attributable to winter weather, as discussed above, this could still add up to a relatively significant annual cost.

5.4.2 Significance of Tourism and Travel in Massachusetts

The Commonwealth's transportation system plays a vital role in supporting tourism activity and related travel as part of the state's economy. The Massachusetts Office of Travel and Tourism publishes an annual report on the economic impact of travel within the Commonwealth. In 2014, domestic and international travelers in Massachusetts spent nearly \$19.5 billion on transportation, lodging, food, entertainment, recreation and incidentals. Domestic travelers accounted for approximately 86% or \$16.8 billion of these expenditures. Approximately 68% of the visitors drove their own vehicles into the state. Domestic travel spending in 2014 generated approximately \$1.06 billion in tax revenues for the both the state and local governments. Each domestic and international travel dollar produced 3.8 cents and 2.4 cents on state and local tax receipts, respectively. Travel spending for 2014 also produced approximately 212,200 jobs and \$7.9 billion in payroll income for Massachusetts residents (U.S. Travel Association, 2015).

SICP personnel are fully aware of the economic stakes involved with minimizing traffic delays during winter weather. The level of importance may be even higher during holiday periods including Christmas, New Years and school vacation weeks, which are peak travel periods for tourism. These economic factors must be balanced with the potential environmental and infrastructure costs of maintaining reasonably safe roads.

5.5 Estimated Economic Impact on Ecosystem Services

Several studies have evaluated the potential economic impact that deicing chemical usage may pose on ecosystem functions including sustaining viable forested areas, clean drinking water, habitat for wildlife, and others. The economic value of ecosystem functions or the potential impact due to a decline in these services is, however, very difficult to quantify given the wide range of site-specific operational and environmental factors to be considered on a case by case basis.

Costanza et al. (1997) developed estimates of the economic value of ecosystem services provided by forested areas, wetlands, lakes and streams. The ecosystem services include water cycling (e.g. infiltration, retention), soil stabilization, nutrient cycling, and recreation. The study estimated the potential level of decline in ecosystem services and associated lost economic value due to road salt applications. For forested areas, the estimated value of degraded services was approximately \$2,198 per acre while for wetlands, lakes and rivers the estimated value for the decline in ecological services was approximately \$30,240 per acre. For forested areas, most of the lost value was related to a reduction in nutrient recycling due to less plant vigor and growth (~\$1,600/ac), followed by an estimated decline in soil stabilization services (~\$345/ac) and recreation value (~\$235/ac). For wetlands, streams and rivers, most of the estimated lost ecological service value was split between water cycling and retention and nutrient cycling, followed by lost recreation value (Costanza et al., 1997). These estimates of economic value for ecosystem services are based on several general assumptions with various degrees of uncertainty and are likely to depend on many location specific conditions.

Based on ecosystem service value estimates developed by Costanza et al. (1997), Kelting and Laxson (2010) estimated the potential impact that road salt usage may have on ecosystem services along roadways within the Adirondack region of New York. The study used model simulations of varying levels of impact and distances from the roadway and determined that typical road salt applications would result in approximately \$2,320 per lane mile in lost or degraded ecosystem services. This estimated impact or decline in economic value assumed a 1% decline in services provided by lakes and rivers and a 5% decline in ecosystem services provided by forested areas. Applying the estimated potential environmental impact rate of \$2.320 per lane-mile, discussed above, to the approximately 15,900 lane-miles maintained by MassDOT results in an estimated environmental impact of approximately \$37 million per year associated with MassDOT road salt usage. This estimate is expected to have a wide margin of error as numerous site specific factors are likely to influence the degree of impact caused by winter maintenance activities and the estimated value of the ecosystem services provided by undeveloped roadside areas. The study concluded that the use of other deicers such as MgCl₂ or CaCl₂ during colder temperatures as well as various technologies and equipment upgrades can substantially reduce the amount of road salt used and its related environmental impacts. MassDOT already has incorporated many of the suggested technologies as well as liquid MgCl₂ to reduce the amount of road salt used on an annual basis.

6

Special Review Procedures

6.1 Introduction

MassDOT plans to prepare a new ESPR on a 5-year cycle with the next ESPR targeted for 2022. In the intervening years, the ESPR is supplemented with Annual Reports that highlight key aspects of the SICP for the most recent winter. Unlike the ESPR, and as described below, the Annual Reports are not subject to the formal review and comment process but are noticed in the Environmental Monitor. This ESPR development process was initially outlined in the MEPA Certificate #11202 issued on December 1, 2006 following the completion of the 2006 GEIR. The ESPR provides a general overview of the potential environmental and socio-economic impacts of MassDOT SICP using the latest data available and relevant research as well as described the various measures being used or planned to mitigate any adverse impact.

6.2 Special Review Procedures for Future MassDOT SICP ESPRs

Consistent with the ESPR process used by other state agencies, MassDOT will prepare one Final version of the next Snow and Ice Control ESPR for public review and comment. Prior to initiating the next ESPR process, MassDOT will develop a Work Plan (WP) that will outline key topics and issues to be included in the next ESPR. In developing this Work Plan, MassDOT will consult with the Massachusetts Department of Environmental Protection (MassDEP), the DCR, and the NHESP to solicit comments on these key topics and issues. Following agency consultations, MassDOT will submit the Work Plan to be noticed in the Environmental Monitor, which will be subject to a 30-day, public review and comment period. During the comment period, a public consultation session will be held to receive additional public input.

Following the comment period on the Work Plan, the Secretary of the Office of Energy and Environmental Affairs (EEA) will issue a MEPA Certificate that formally outlines the key issues and concerns to be included in the next ESPR. MassDOT will prepare a single ESPR that will be noticed and made available for agency and public review through the Environmental Monitor for a period of 37 days. This includes a 30-day public comment and a 7-day period to develop a MEPA Certificate. The Secretary of the Executive Office of Energy and the Environment will issue a MEPA Certificate that summarizes the agency and public comments, which will be used to develop the work scope for the next ESPR. The ESPR distribution list will include individuals or organizations that commented on the Work Plan and the ESPR 5 years prior. MassDOT will prepare Annual Reports in the intervening years that will provide and update on operational

practices, material usage and winter severity conditions for the previous winter and will be submitted to the EEA Office by December 31st to be published in the Environmental Monitor.

Table 6.1 summarizes a proposed timeline for key activities/deliverables as part of a future MassDOT SICP ESPR development process:

Table 6.1: Proposed Timeline for Major Deliverables for Future MassDOT SICP ESPR Development Process

Activity/ Report	Anticipated Timeline	Agency Consultation/Public Review Process	EEA Response
Annual Report	By December 31 st of each intervening year	Published in Environmental Monitor (EM)	No MEPA Action
Work Plan	~ 18 months prior to targeted Final ESPR	Agency consultation, published in EM, public comment period and public consultation session	MEPA Certificate Issued
Final ESPR	~ 2 years after Work Plan	Published in EM	MEPA Certificate Issued

Planned Future Initiatives

The following represent some of the principal future initiatives that MassDOT plans to incorporate over the next five (5) years to improve the efficiency or effectiveness of material usage as well as their reporting capabilities as part of their Snow & Ice Control Program.

1. Enhance the employee and contractor training program, through consultation with other state transportation agencies, to explore other methods to deliver content and increase the level of understanding of the technical aspects and science behind snow and ice control practices.
2. Install pavement friction and pavement temperature sensor equipment on all District Supervisor vehicles to provide another tool to help determine when deicing material may be needed during winter events and help monitor and document road surface conditions.
3. Construct a new brine manufacturing facility in Deerfield within the next two years to increase brine availability for pretreatment and prewetting in Districts 1, 2, and 3. Investigate the feasibility of constructing additional brine facility to service District 4.
4. As funding allows, continue to expand the availability of tanker trucks, brine storage and overall roadway pretreatment capabilities especially in key environmentally sensitive areas
5. Ensure that calibration vendors submit written evidence of being certified by manufacturers to calibrate specific material spreader equipment.
6. Consult with calibration vendors to ensure that they mark the gate openings on hired equipment and submit copies of calibration certificates for each vendor truck they calibrate. Prior to the 2016-17 winter season, vendor trucks were only required to have a copy of the certificate in the vehicle.
7. Implement the use of GPS/AVL equipment with a goal of having all contractors using GPS/AVL equipment by 2022. The GPS/AVL equipment will allow MassDOT to collect more vehicle and route specific information regarding the timing and rate of application, and roadway condition data.
8. Reduce and eventually eliminate the use of sand in RSZs by expanding or adding new efficiency measures and technologies to achieve better snow removal, improved forecasting and more efficient material usage in RSZs as well as along other MassDOT maintained roadways.
9. Continue to use and research potential new approaches to enhance the Winter Severity Index (WSI) as a means to monitor salt use efficiency relative to historical usage under similar winter weather severity.

10. Continue to evaluate the statewide vehicle accident rates during winter months compared to non-winter months to assess how well roadway surface conditions are being maintained.
11. Continue to explore the use of variable messaging signs and varying ways to modify messages to inform the traveling public of impending weather and potentially slippery road conditions in order to affect driver behavior and reduce speeds.
12. Continue to participate in the pooled-funded research efforts, as appropriate, under the ClearRoads Program to explore new technologies and measures to reduce material usage and improve road surface conditions during winter weather.
13. Continue to explore new bridge design and maintenance methods to protect roadway infrastructure from the potential corrosion effects related to road salt usage.
14. Continue to upgrade and replace storage sheds throughout the state as funding allows with high roof type sheds that allow material offloading and loading indoors.

8

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Appendices

Appendix A:

MEPA Certificate & Comment Letters



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September 1, 2017

**CERTIFICATE OF THE SECRETARY OF ENERGY AND ENVIRONMENTAL AFFAIRS
ON THE 2017 DRAFT SNOW AND ICE CONTROL PROGRAM
ENVIRONMENTAL STATUS AND PLANNING REPORT**

PROJECT NAME	: 2017 Draft Snow and Ice Control Program Environmental Status and Planning Report
PROJECT MUNICIPALITY	: Statewide
PROJECT WATERSHED	: Statewide
EOEA NUMBER	: 11202
PROJECT PROPONENT	: Massachusetts Department of Transportation
DATE NOTICED IN MONITOR	: July 12, 2017

As Secretary of Environmental Affairs, I hereby determine that the 2017 Draft Snow and Ice Control Environmental Status and Planning Report (DESPR) adequately and properly complies with the Massachusetts Environmental Policy Act (M.G.L. c.30 ss.61-62) and its implementing regulations (301 CMR 11.00). The Massachusetts Department of Transportation (MassDOT) should prepare its 2017 Final ESPR (FESPR) in accordance with the requirements of this Certificate, including responses to comment letters.

Project Description

The purpose of the ESPR is to describe the methods and policies used by the Massachusetts Department of Transportation's (MassDOT) Snow and Ice Control Program (SICP). It documents the environmental impacts of these practices and identifies the Best Management Practices (BMPs) used to minimize these impacts while providing safe roadway driving conditions. The DESPR documented the environmental data, road safety requirements, and economic factors used by MassDOT to plan for and implement the SICP with the goal of protecting sensitive resource areas, particularly public water supplies and wetland and aquatic ecosystems. The series of ESPRs filed by MassDOT document the historical changes and trends

in the use of materials, equipment, storage practices, and snow and ice control practices and provide an opportunity to identify and prioritize aspects of the SICP that may be improved.

History and Purpose of the ESPR

MEPA review of MassDOT's snow and ice control procedures commenced with the filing of Generic Environmental Impact Reports (GEIR) in 1978, 1995, and 2006. Revisions to the MEPA regulations in 1998 eliminated provisions for the preparation of GEIRs. In connection with the issuance of the Certificate on the GEIR in 2006, a Special Review Procedure (SRP) was established to substitute for the submittal of GEIRs with ESPRs. The SRP outlined a process where ESPRs would be prepared on a five-year cycle. Each cycle would commence with the filing of a Draft Scope of Work (DSW) by MassDOT to identify the information and analysis to be provided in a DESPR. After review of the DESPR, a FESPR would then be prepared to provide any additional information and analysis necessary to address comments by State Agencies, the public and the requirements of the MEPA Certificate on the DESPR. MassDOT also prepares annual Snow and Ice Control Annual Reports that are noticed in the Environmental Monitor but not subject to a formal comment or review process.

The ESPR process does not replace MEPA review of roadway projects that require a State Agency Action and meet or exceed regulatory thresholds. For any project that does exceed thresholds, an Environmental Notification Form (ENF) and, if necessary, an Environmental Impact Report (EIR) would be required to analyze impacts, review alternatives and identify measures to avoid, minimize, and mitigate impacts. The ESPR process serves as a vehicle for public review of the environmental impacts associated with the SICP. It is creating a long-term data set that provides the opportunity to gauge the effectiveness of efforts to minimize impacts, and can serve as the basis for prioritizing future planning and implementation measures.

Review of the DESPR and Scope

General

The DESPR was generally responsive to the Scope outlined in the Certificate on the 2016 DSW. Major elements of the DESPR included:

- An overview of the Snow and Ice Control Program's organization, policies and operations;
- A description of the latest equipment improvements, technologies, and Best Management Practices (BMPs) used by MassDOT for roadway snow and ice control;
- An update on the latest environmental protection/remediation activities and related research pertaining to environmental issues concerning snow and ice control activities;
- Updated information on the added infrastructure costs associated with the corrosion effects from deicing chemical usage and the economic benefits of maintaining safe travel conditions on roadways during winter weather;
- A review of the SRP and proposed changes to MEPA review of future ESPRs; and
- A list of goals and initiatives for the SICP to be implemented over the 5 year period prior to filing of the next ESPR.

The DESPR reviewed MassDOT's Reduced Salt Zone (RSZ) program, provided an update on salt remediation activities and responded to comments received on the DSW.

MEPA review of MassDOT's snow and ice control practices has been traditionally limited to the environmental impacts and potential mitigation measures related to the use of de-icing agents for roadway clearing, with particular emphasis on water supplies, wetlands and aquatic resources. WalkBoston recommends that the scope of ESPRs should be expanded to include policies and practices related to clearing of sidewalks, curb ramps and crosswalk islands. Inadequate clearing or plowing practices that block pedestrian facilities could have negative consequences for pedestrian access and may conflict with MassDOT's policies for improving and maintaining pedestrian and bicycle facilities throughout the Commonwealth.

The FESPR should include a response to Walk Boston's comments. To the extent it is available, the FESPR should provide basic information and data on the roadways subject to the SICP that have pedestrian and bicycle facilities and any practices or policies intended to maintain access to these facilities. The FESPR should address any current coordination between MassDOT and communities to maintain pedestrian and bicycle facilities in the winter.

The FESPR should respond to comments submitted by Massachusetts Department of Environmental Protection (MassDEP), the Cambridge Water Department (CWD) and the Connecticut River Conservancy. Where applicable, the responses should include revisions to the relevant portions of the DESPR, including the proposed initiatives listed in the DESPR. MassDOT should identify any additional analyses or data collection recommended by commenters that it will consider for inclusion in the next ESPR.

Snow and Ice Control Practices

MassDOT maintains approximately 16,000 lane miles of roadways, or 20 percent of the total lane-miles in the Commonwealth. The cost of the SICP averages \$100 million per year, which can fluctuate greatly depending on the severity of the winter weather. According to the DESPR, sidewalk clearing is generally the responsibility of local communities. MassDOT has curb-to-curb snow and ice removal responsibility for the Department of Conservation and Recreation's (DCR) parkways in the Boston area. In accordance with its Standard Operating Guide for Winter Weather Events, DCR clears snow and ice from some of its roadways, and pedestrian routes.

The deicing agents used by MassDOT include sodium chloride either as granular road salt or a liquid brine solution; a premix of four parts road salt and one part calcium chloride delivered as flakes or liquid; sand, usually in a 1:1 mix with road salt; and liquid magnesium chloride. Each have been used for specific purposes and have both benefits and detriments. Road salt is the predominant deicing material because of its availability and lower cost (approximately \$60 to \$80 per ton); an average of nearly 507,000 tons of road salt have been used annually since 2013. It is generally applied at a rate of 240 pounds (lbs) per lane mile in order to prevent snow and ice from bonding to the pavement. Road salt is less effective when temperatures are below 20 degrees Fahrenheit (F). Premix is used in RSZs to minimize the release of sodium chloride near water supplies. With a cost of approximately \$200 per ton, it is considerably more expensive than road salt. On average, 1,656 tons of premix have been used annually since 2013. Sand mixed with road salt is also used in RSZs to minimize road salt

application. Sand is inexpensive, but it provides minimal traction for vehicles and its accumulation creates environmental impacts and additional drainage system maintenance requirements. Compared to historical usage of approximately 100,000 tons per year (tpy), only approximately 20,000 tons of sand have been used each year over the last six years.

Liquid deicers are used to pre-treat roadways and pre-wet road salt before it is applied. They help improve roadway conditions while minimizing the use of road salt. Pre-treating roadways with liquid magnesium chloride can help prevent ice from forming and delay the need to apply road salt. MassDOT used an average of 1.36 million gallons of liquid magnesium chloride per year since 2013, compared to 138,730 gallons of liquid brine per year and 7,102 gallons of liquid calcium chloride per year. Liquid magnesium chloride is less corrosive than liquid calcium chloride and works better than brine solution at low temperatures. Road salt has been shown to be more effective if it is pre-wetted with a liquid deicer. Pre-wetting can reduce the amount of salt that is used because it helps road salt adhere to the roadway surface and prevents dry salt from being wasted when it bounces off the pavement. Because of the benefits of pre-wetting, MassDOT requires that all road salt spreaders have pre-wetting equipment.

MassDOT uses a Winter Severity Index (WSI) to help evaluate its efforts to reduce road salt usage over time under varying winter weather conditions. The WSI is calculated based on characteristics of each winter season, including daily snowfall, daily minimum and maximum temperatures and on the number of days with frost potential. It is calculated for each winter month, then averaged for a five-month period (November to March) to provide a seasonal average. The WSI is a tool to help explain how weather conditions influence MassDOT's use of road salt from year to year and provides a means of evaluating the effectiveness of upgrades in material and equipment and technological advances. During a 10-year (2001 to 2010) baseline period, trends in salt use correlate with the severity of a winter as measured by the WSI. A regression analysis of this baseline period serves to predict salt use for a given WSI. This baseline period preceded significant changes to the SICP operations, such as pre-treatment and pre-wetting. According to the DESPR, salt use levels below those predicted based on the correlation between WSI and road salt application rate reflect reductions in road salt use due to improvements in the SICP. The DESPR documented that, pro-rated on the basis of WSI, salt use has declined approximately 25 percent since the SICP incorporated the modified deicing practice described above. As recommended by the Cambridge Water Department (CWD), future ESPRs should use a baseline developed with more recent data so that the benefits of ongoing changes to the SICP can be evaluated.

Environmental Protection Measures and Remediation

The DESPR summarized MassDOT's Salt Remediation Program and RSZ policy, reviewed data on sodium and chloride in public water supplies and other environmental impacts of the SICP and reviewed pilot projects underway in sensitive ecological areas.

The Salt Remediation Program provides mitigation to address elevated levels of sodium to owners of impacted wells. MassDOT conducts sampling and hydrogeological investigations to determine whether its practices are the cause of the elevated sodium levels. Mitigation measures include replacement or rehabilitation of an existing well, connecting the property to a PWS, or installation of a water treatment system. In the last five years, 56 claims were filed compared to 68 claims in the previous five-year period.

The RSZ program covers 62 areas (1,752 lane-miles) that are located primarily in Zone III Wellhead Protection Areas. RSZs are designated by MassDOT through a formal process that begins once the designation is requested by a water supplier or private homeowner. MassDOT's review of a request for RSZ designation includes site investigations to evaluate whether SICP operations are contributing to elevated sodium levels. The RSZ program is intended to reduce salt use in areas with elevated sodium levels that are likely due to SICP activities. MassDOT estimated that it costs an additional \$2,000 more per lane mile on an annual basis to treat roadways in RSZs. The additional costs are due to the use of liquid magnesium chloride, extra personnel time needed to monitor roadway conditions, and additional maintenance of drainage facilities because of the sand mix that is applied to roadways. According to the DESPR, application of the sand and salt mix reduces the amount of sodium used in RSZs by 40 percent, however, MassDOT indicates that the mix is less effective in controlling snow and ice than road salt and requires more frequent applications. Last year MassDOT commenced a pilot program in which it evaluated the effectiveness of using road salt alone in RSZs. The road salt was applied at a lower rate and less frequently than in areas outside of RSZ. Preliminary results of the pilot project suggested that it reduced the amount of salt used in RSZ and eliminated impacts associated with sand. The FESPR should clarify under what conditions liquid magnesium chloride is used to pre-treat roadways in RSZ and describe the benefits of pre-treatment in connection with the use of road salt and road salt/sand mix.

The DESPR reviewed available data on sodium and chloride levels in Public Water Supplies (PWS) near MassDOT roadways. Public water supplies within 0.5 miles of a MassDOT roadway were more likely to exceed the 20 milligram per liter (mg/l) standard for sodium in drinking water supplies; however a regression analysis found no relationship between distance from a MassDOT roadway and sodium concentrations. The DESPR also reviewed data for chloride levels in PWS and found that only 30 out of 475 (eight percent) of PWS exceeded the chloride standard of 250 mg/l.

While acknowledging the success of the SICP in reducing the amount of road salt applied to roadways, MassDEP and CWD noted that sodium and chloride levels in drinking water supplies continue to increase. According to MassDEP, sodium concentrations at several PWS in northeastern Massachusetts have doubled since the 1990s. Water samples collected by the CWD from its water supply reservoirs adjacent to Route 128 document rising levels of sodium and chloride during the 5-year period covered by the DESPR. Comments from MassDEP suggested additional data collection and statistical analysis that should be used by MassDOT to evaluate the environmental effects of the SICP. MassDOT should consider MassDEP's comments and identify additional analyses that it will consider for the next ESPR. The CWD and MassDEP requested that MassDOT conduct a comprehensive study of salt inputs into a watershed so that the relative contribution of MassDOT, municipal and private sources can be better understood. The FESPR should outline the elements of a watershed-based study and identify the level of data collection and analysis that would be required and discuss its feasibility. It should identify opportunities for collaboration with State Agencies and communities and potential funding sources, including grants.

The DESPR reviewed the potential impacts of the SICP to sensitive ecological areas adjacent to MassDOT roadways, including Areas of Critical Environmental Concern (ACEC), aquatic resources, rare species habitat, roadside vegetation and maple sugaring. It summarized

studies of road salt impacts to Kampoosa Bog in Stockbridge and Lee, which indicate that sodium and chloride concentrations were generally limited to an area extending 300 meters from the roadway and that half of the sodium and chloride applied to the Mass Turnpike was flushed out of the watershed in the spring. MassDOT has initiated a pilot study on roadways adjacent to Kampoosa Bog. The pilot study is evaluating the effectiveness of electronic tracking application of road salt by spreaders in order to more consistently apply the desired amount.

Existing Best Management Practices for Improving Road Salt Use Efficiency

The DESPR described the various technologies, equipment upgrades, and policy changes adopted by MassDOT to improve the effectiveness and efficiency of the SICP while minimizing the use of road salt. As described earlier, the most effective techniques have involved the use of liquid deicers to pre-treat roadways and pre-wet road salt. The DESPR evaluated alternative deicing agents, such as calcium magnesium acetate (CMA), potassium acetate (KAc), sodium acetate (NaAc) and other organic-based compounds. According to the DESPR, the organic deicing agents are less corrosive than salt, they are much more expensive and have been shown to impact biological oxygen demand (BOD) in water bodies.

MassDOT has adopted new snow and ice control technologies that have been proven effective in providing safe roadway conditions while reducing the use of road salt. These technologies include mobile pavement sensors, Road Weather Information Systems (RWIS), closed-loop computer controllers on salt trucks, and tow plows that more efficiently remove snow. MassDOT is also conducting a pilot project to evaluate the use of a Global Positioning System/Automatic Vehicle Locator (GPS/AVL) system, which incorporates GPS software and equipment to set-up geo-referenced boundaries in key locations to automatically adjust or cease applications as spreader trucks travel along spreader routes. Front-end loader weigh scales, which help increase accuracy of road salt use, are also being evaluated.

The FESPR should identify technologies that will continue to be used or evaluated prior to the preparation of the next ESPR. The FESPR should generally describe any formal tracking or evaluation criteria used for determining the effectiveness of snow and ice control technologies.

Revisions to the Special Review Procedure

During the review period, MassDOT circulated proposed revisions to the SRP. The proposed revisions would modify the ESPR process to more closely follow the format used by the Massachusetts Port Authority's (Massport) Hanscom Field (EEA #5484/8696) and Logan Airport (EEA #3247) ESPRs. MassDOT proposed to file a Work Plan, which would be noticed in the Environmental Monitor for public review and comment. A Consultation Session would be held during the review period. Within 18 months of the issuance of the Certificate on the Work Plan, a single ESPR would be submitted for public review and comment. The single ESPR would replace the DESPR and FESPR now provided by MassDOT. The filing of ESPRs would continue to be on a 5-year cycle. Prior to filing the FESPR, MassDOT should consult with MEPA staff to prepare a draft SRP to be included in the FESPR for public review and comment.

Future Initiatives

The DESPR listed initiatives that MassDOT intends to implement prior to filing the next ESPR. The initiatives include:

- Additional snow and ice control training programs;
- Installation of pavement friction and pavement temperature sensors to help determine when deicing material may be needed;
- Construction of a new brine manufacturing facility in Deerfield;
- Expansion of pretreatment in salt sensitive areas;
- Ongoing monitoring of spreader equipment calibration;
- Expansion of the use of GPS/AVL systems;
- Reduction of the amount of salt applied in RSZ by using better plowing methods, improved forecasting and minimizing salt application rates;
- Exploration of the use of variable message signs to inform travelers of roadway conditions and road speeds;
- Continuation of participation in research projects to explore new technologies and methods for reducing salt use, including use and standardization of vehicle-mounted sensor equipment, updated material application guidelines and BMPs, performance of porous pavements, and enhanced snowplow training and operations;
- Review of potential anti-corrosion methods; and
- Replacement and/or upgrade of salt storage sheds.

Circulation

The 20017 FESPR should be circulated in compliance with Section 11.16 of the MEPA regulations and copies should be sent to the list of “comments received” at the end of this Certificate. A copy of the 2017 FESPR should be made available for public review at the State Transportation Library.

Conclusion

The 2017 FESPR should include a copy of this Certificate, and it should be made available in printed or CD-ROM format. The FESPR should be submitted in 2017 and include the most recent data available.



September 1, 2017

Date

Matthew A. Beaton

Comments received:

08/07/2017 Massachusetts Division of Fisheries and Wildlife – Natural Heritage and Endangered Species Program (NHESP)
08/09/2017 WalkBoston
08/11/2017 Connecticut River Watershed Council
08/23/2017 Cambridge Water Department
08/25/2017 Massachusetts Department of Environmental Protection (MassDEP)

MAB/AJS/ajs



Department of Environmental Protection

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Charles D. Baker
Governor

Matthew A. Beaton
Secretary

Karyn E. Polito
Lieutenant Governor

Martin Suuberg
Commissioner

August 25, 2017

Mr. Alex Strysky
MEPA Unit
100 Cambridge Street, 9th Floor
Boston, MA 02114

RE: MassDOT Snow and Ice Control Program 2017 Environmental Status and Planning Report (ESPR)
MEPA #11202

The Massachusetts Department of Environmental Protection's (MassDEP)'s Bureau of Water Resources appreciates the opportunity to review and provide these comments on the above-referenced Environmental Status and Planning Report. MassDEP's comments provide relevant background information and request certain actions to allow MASSDOT and MassDEP to better evaluate and implement measures to protect public drinking waters (both surface and groundwater supplies), in-water uses, wetlands, and aquatic organisms.

The MassDOT Snow and Ice Control Program (SICP) 2017 ESPR is a comprehensive document covering snow and ice removal and control operations, corrosion damage to roadway infrastructure and vehicles, deicing chemicals usage and management practices to balance public safety with environmental protection. It is appreciated that MassDOT, through the SICP, discusses the snow and ice control technologies and alternative deicers it utilizes to maintain the public safety and protect our environmental and public health. It is also recognized that road salt applications are based on the winter severity index.

1. Sodium (Na) and Chloride (Cl) are the two major chemicals of concern to protect waters and wetlands from the impacts of road salt. The Na threshold for public drinking waters is 20 mg/L and the Cl threshold is 230 mg/L for chronic toxicity to aquatic organisms. The environmental goal of the MassDOT snow and ice removal practices should be to maintain waters and wetland resource areas adjacent to highways below 20 mg/L for Na and 230 mg/L for Cl, during the winter months. MassDEP recommends that the ESPR provide more comprehensive analyses of both Na and Cl data.
2. For non-Chloride based deicers and anti-icers (such as acetates), biological oxygen demand (BOD) is of concern, since acetates reduce oxygen in waters and wetlands that support aquatic organisms including fish. MassDOT currently is not reporting that it uses acetates to deice

roadways. However, if MassDOT switches to acetates to reduce Na and Cl loading to waters and wetlands, we request that MassDOT consult with MassDEP to determine target BOD limits in waters and wetlands that should not be exceeded during the winter months.

3. Regarding data analyses of Na and Cl in Public Water Supplies (PWS) and the interpretation on their association with MassDOT roads (Pages ES-4 and 2-4 to 2-6), MassDEP recommends MassDOT perform enhanced statistical analyses to find out whether or not the higher concentration of sodium or chloride within a 0.5-mile of MassDOT roadway is a result of MassDOT SICP operations. If the concentration value (mg/L, Sodium or Chloride) is used, then a T-test is suggested. If the percentage of reported concentrations within a range is used, then non-parametric statistics are recommended. MassDEP is available to MassDOT for technical consultation on this.
4. In order to quantify the Na and Cl contribution directly caused by MassDOT road salt application, more detailed studies on targeted sites are needed. For MassDOT SICP's Planned Future Initiatives, MassDEP recommends that MassDOT do one or multiple pilot studies to quantify the contribution to the targeted site(s) from MassDOT road salt application in terms of loading of sodium and/or chloride. (Pages ES-4 and 2-5)
5. MassDEP questions the validity of the statement that "In fact, the data suggests that there is no clear correlation or relationship between sodium levels in PWS wells and distance to a MassDOT roadway" (Page 2-6). Figure 2.3 appears to show that it is more likely that within 0.5 mile of a MassDOT roadway, PWS wells have higher sodium concentrations. MassDEP recommends that the model be re-run and statistical analyses be performed in consultation with MassDEP using a more complete dataset including samples beyond a 0.5 mile radius of MassDOT roadways. MassDEP is available to MassDOT for technical consultation on this.
6. In view of the different chloride-based products being applied to highways including Sodium Chloride, Liquid Magnesium Chloride, and Salt Brine, MassDEP requests that MassDOT use a common metric to assess the total amount of chloride applied to roads, such as total chloride concentration. Without a common metric, it is difficult to judge whether total chloride concentrations are being reduced.
7. Figure 1.5 indicates that recent efficiency measures and equipment upgrades have resulted in reduced road salt use. MassDEP recommends that MassDOT provide analysis of covariance (ACOVA) to determine whether the reductions are statistically significant, especially since road salt use will vary as evidenced by the winter severity index.
8. Given the limited data for each town in Table 2.4 on Page 2-8 and Appendix B, MassDEP requests that MASSDOT run some non-parametric trend analyses, such as Kendall trend analysis, to determine if there are any statistical changes in sodium concentrations. The critical threshold to analyze in the Kendall trend analysis must set to $\alpha \leq 0.05$. MassDEP is available to MassDOT for technical consultation on this.
9. Since the 1990s, sodium concentrations at several public water supplies in Northeastern Mass that receive runoff from MASSDOT highways have doubled. During this period, MassDOT and several municipalities have gone from applying a sand-salt mixture to application of only salt and salt derivatives. While MassDEP has noted the decrease in salt application that MassDOT has achieved through its new deicing practices, MassDEP has not yet observed a decrease in the sodium concentration at the affected public water supplies. MassDEP does not have data to separate out the sodium inputs to these supplies from MassDOT highway runoff, municipal deicing application, private contractor application to parking lots, etc. MassDEP recommends that MassDOT estimate its impact using methods such as those described in Heath and Morse 2013, which analyzed road salt impacts to wellfields in Wilmington located adjacent to Route I-

93, including separating road salt applied by MassDOT, the Town of Wilmington, and local contractors.

10. In MassDEP's May 20, 2016 comment letter to MEPA on the ESPR Work Plan, we had asked that MassDOT evaluate the areas on the Mass Turnpike within Zone II and Zone A designations to see if more Reduced Salt Zones are warranted. MassDEP asked for this because the Mass Turnpike had been incorporated into the MassDOT roadway network after the development of the last ESPR in 2012. MassDEP also asked if the process for RSZ designations had been improved to be made easier for the applicant because of the challenging nature of the application process currently in use. MassDEP recommends that MassDOT address these two issues in the Final ESPR to describe what efforts, if any, have been made to facilitate municipalities' applications and the designation of RSZs to protect public health.
11. On page 2-4, it is stated that the sodium data from public water supplies within the Cape Cod region that are near MassDOT roads have relatively low sodium concentrations. This may be due to those wells drilled deeper and screened deeper in the aquifer. The Cape Cod aquifer is much deeper than the rest of the state and therefore is pulling water from greater depths with more sodium-free groundwater mixing from both above and below the well screen. In theory, the contributing groundwater to these deeper wells is made up of a higher percentage of water that is not impacted by road salt. MassDEP recommends that MassDOT evaluate data on the depth of PWS source to better assess the ESPR's finding.
12. Page 2-0 of Section 2.3 (Salt Remediation Program) states the thresholds for additional sampling to be done by MassDOT regarding complaints initiated by private well owners. It does not state anywhere what the thresholds are that would result in additional MassDOT sampling for Public Water Supplies. MassDEP recommends that MassDOT establish thresholds for the evaluation of impacts to Public Water Supplies.
13. The statement on Page 2-4 that all Public Water Systems are required to test for sodium in their raw water and treated water is incorrect. It is also incorrect that sodium testing of all individual sources is required if any one of the sources has an elevated sodium level. Public Water Systems that have their own water sources are required in accordance with 310 CMR 22.06A to test for sodium at each entry point to the water distribution system — this location is after any water treatment has been done, and often includes blended water from multiple wells and/or reservoirs. Testing of sodium in raw water is not required by 310 CMR 22.06A, though MassDEP has the regulatory authority under 310 CMR 22.03(2) to require raw water testing if deemed necessary in a particular case. (Page 2-4, under section 2.4.1.)
14. Page 2-7 states that sodium levels in the Town of Reading have decreased in recent years. Reading shut down all of its municipal wells in 2006 when it joined the Massachusetts Water Resources Authority. The last data point in the Appendix B graph for Reading was in 2005. Reading is not relevant to a discussion of recent trends at public water supplies, particularly as it relates to deicing practices implemented since 2010. MassDEP suggests that this reference be deleted, and the analysis re-conducted without Reading data.
15. The City of Cambridge is not one of the public water systems included in the Section 2.4 evaluation, or Appendix B. Cambridge's reservoirs receive runoff from Rtes. I-95/128 and Rte. 2. The watershed of these reservoirs has long been a Reduced Salting Zone. The sodium level in the Cambridge public water system has continued to rise since the implementation of the current MassDOT deicing practices. The City of Cambridge reservoir system that receives runoff from Routes I-95/128 and Route 2 should be included, and MassDEP recommends that MASSDOT revise their data analysis to include the evaluation of sodium data for this source into section 2.4 or Appendix B, because sodium levels continue to rise in a reduced salt zone for a

water supply serving a densely populated area. MassDEP also requests further evaluation of additional measures to address sodium in Public Water Supplies.

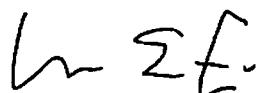
16. On page 2-10 it is stated that PWS' that are adding salt to treat for hardness may represent a significant source of the chloride levels. That may also result in higher sodium levels. Also, some PWS' use NaOH instead of KOH for pH adjustment which can also increase the sodium concentration in the source. MassDEP asks that MassDOT evaluate these uses for their contribution to sodium sources, which may affect future control measures.
17. MassDEP requests that MassDOT integrate its snow and ice control program with its permit obligations specified in the MS4 permit issued jointly by the U.S. EPA and MassDEP, including for stormwater runoff discharged to adjacent waters and wetlands.
18. MassDOT and its contractors rinse vehicles that are used in road salting to reduce corrosion to those vehicles. Section 1-4 Vehicle Washing Policy: Mass DOT's "strict vehicle washing policy" requires rinse water to be sent to a closed-drain system (i.e., holding tank) or a municipal sanitary sewer system. There are a number of MassDOT's depots that do not have either a rinse water holding tank, nor a connection to the municipal sewer system. MassDEP recommends that MassDOT ensure that all its depots meet the strict vehicle washing policy by a specific date.
19. Regarding stormwater BMPs, MassDEP requests that MassDOT continue to monitor emerging BMP technologies used by other states to identify BMPs capable of effectively treating sodium and chloride in stormwater. (Section 1-7).
20. MassDEP requests that MassDOT examine how to modify road salting practices to prevent the export of phosphorus to nutrient impaired waters from "constructed stormwater treatment wetlands" in order to meet Total Maximum Daily Load (TMDL) requirements. Road salt in runoff that is directed to "constructed stormwater treatment wetlands" has encouraged invasive species growth, increasing phosphorus export, lowering water quality.
21. Section 2-2 Reduce Salt Zone areas: MassDEP notes that the additional per lane costs in RSZ areas (\$2,000 per lane mile) are somewhat less than the average costs of economic impacts (approximately \$2,320 per lane mile) due to lost or degraded ecosystem services (see page E-6). Since those costs are higher where salt impacts public water supplies, MassDEP asks MassDOT to reconsider its current data requirements for establishing RSZ areas where the cost of impacts exceeds the estimated additional program costs impacts.
22. Regarding impacts on aquatic organisms, in MassDEP's 2016 comment letter to MEPA, MassDEP had indicated it would be helpful for "MassDOT to assess where the road salt from State highways is causing streams and wetlands to exceed the National Recommended Water Quality Criteria for chloride for acute and chronic toxicity to aquatic organisms." MassDEP requests that MassDOT identify the specific streams and wetlands located adjacent to MassDOT highways where road salt directed from highways to those streams and wetlands is exceeding the 230 mg/L Chloride threshold established by the National Recommended Water Quality Criteria. Data collections should include evaluations of seasonal variations, including sampling in winter and spring.
23. MassDEP requests that MassDOT establish no-salt or limited salt areas when roadways pass through Zone IIs of subsurface groundwater supplies and critical water resource areas, such as cold-water fisheries.
24. **Typographical Errors:** MassDEP has identified the following typographical errors:
 - a. Page 1-15 should say 17 years instead of 16 years in the first sentence of the 2nd paragraph.
 - b. A reference is needed for the following statement on Page 1-8: MassDOT's standard road salt application rate is 240 lbs per lane-mile, which is generally considered the

minimum needed to prevent snow and ice from bonding to the pavement under a range of temperature and precipitation conditions.

- c. Page numbers in Section 2 need correcting.
- d. Page 2-6 reads "The date indicates that many wells located to a MassDOT ..." – "date" should be replaced by "data".
- e. On Page 2-6, the reference to "2.3.3" in the following sentence should be "2.4.3" ("The WPI study authors noted that sodium levels in water supply wells appear to be trending upward, which is discussed in Section 2.3.3 below and depicted... ")
- f. The first sentence, second paragraph on Page 2-22 states, "Smith and Granato (2010) reported that the average sediment and phosphorus concentrations in highway runoff from principal roadways were found to be 3 to 10 higher in winter months compared to that in non-winter months." There is a word missing before "higher" in this sentence. Is this "3 to 10 times higher"? "3 to 10 percent higher"?
- g. The reference is needed for the last paragraph on Page ES-6 that describes a recent study on reduced or lost ecosystem services provided by adjacent and wetland areas along roadways treated with road salt.

Please feel free to contact me if you have any questions about MassDEP's comments.

Sincerely,



Douglas E. Fine
Assistant Commissioner
Bureau of Water Resources

Strysky, Alexander (EEA)

From: Paulson, David (FWE) <david.paulson@massmail.state.ma.us>
Sent: Monday, August 07, 2017 1:47 PM
To: Strysky, Alexander (EEA)
Cc: Holt, Emily (FWE)
Subject: MassDOT Snow and Ice Control Program 2017 Environmental Status and Planning Report (11202/06-20527)

Secretary Matthew Beaton
Executive Office of Environmental Affairs
Attention: MEPA Office
Alex Strysky, EEA No. 11202
100 Cambridge St. Suite 900
Boston, Massachusetts 02114

Project Name: Snow and Ice Control Program
Proponent: MassDOT
Location: Statewide
Document Reviewed: Snow and Ice Control Program 2017 Environmental Status and Planning Report
EEA No.: 11202
NHESP No: 06-20527

Dear Secretary Beaton:

The Natural Heritage & Endangered Species Program (NHESP) of the MA Division of Fisheries & Wildlife (DFW) has reviewed the *MassDOT Snow & Ice Control Program 2017 Environmental Status and Planning Report*, and the NHESP would like to offer the following comments regarding state-listed rare species and their habitats.

We have recently reviewed the MassDOT Snow & Ice Control Program 2017 Environmental Status and Planning Report. The NHESP appreciates the recognition of the documented effects that road salt has had on the chemistry and species composition of Kampoosa Bog. In addition, the NHESP recognizes MassDOT's advancements in technology leading to reductions in salt application statewide.

The NHESP believes that review through the MEPA process of the MassDOT Snow & Ice Control Program 2017 Environmental Status and Planning Report presents a great opportunity for MassDOT and NHESP to continue to meet and discuss Snow & Ice Control BMPs when working in ecologically sensitive areas (i.e. Kampoosa Bog). Further, the Division looks forward to the ongoing reach and monitoring efforts associated with Kampoosa Bog.

We appreciate the opportunity to comment on this Report. If there are any questions about the NHESP portion of this letter, please contact David J. Paulson, Endangered Species Review Biologist, at (508) 389-6366.

David Paulson
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August 11, 2017

Secretary Matthew A. Beaton
EOEEA, Attn: MEPA Office
Alex Strysky, EEA No. 11202
100 Cambridge Street, Suite 900
Boston, MA 02114

**Subject: 2017 Environmental Status and Planning Report for EOEA# 11202
MassDOT Snow and Ice Control Program, Public Review Draft, June, 2017**

Dear Secretary Beaton,

I am submitting comments on the Public Review Draft for the 2017 Environmental Status and Planning Report (ESPR) for the Massachusetts Department of Transportation's (MassDOT's) Snow and Ice Control program on behalf of the Connecticut River Conservancy (CRC). CRC is the principal nonprofit environmental advocate for protection, restoration, and sustainable use of the Connecticut River and its watershed. Until April of 2017, we were known as the Connecticut River Watershed Council (CRWC). Because the Connecticut River and its major basin tributaries take up approximately one-third of Massachusetts, MassDOT's approach to snow and ice removal has a significant effect on our watershed. We recognize the challenge in keeping roadways safe, yet trying to apply de-icing chemicals in a quantity that is not overly detrimental to the environment. We have submitted comments on the ESPR and related documents for the last decade.

Our primary comment is on the presentation of data to make the case that salt use has been reduced over the years.

- In the 2012 draft ESPR, Table 1-3 provided a summary of MassDOT annual salt usage for each district from FY 2002-2011. This table presented total tons/year for each district and state-wide for a period of 10 years, including a 10-year average for each district. Figures 1-2 and 1-3 showed salt use in tons and salt use by lane mile for MassDOT by District for fiscal years 2002-2011. The report included some discussion of why certain districts had a higher salt usage amount. In the 2017 draft ESPR, there is no information about salt application by district, or total tons applied statewide.
- In the 2012 draft ESPR, Figure 1-6 showed a comparison of the statewide annual salt usage (in tons) with average monthly WSI values for FY01-FY11. The 2017 draft ESPR, Figure 1.6 added FY12-FY17 but showed the data by tons/lane mile, which differs from the earlier way the data was presented (tons/year).
- Table 1.4 of the 2017 draft ESPR shows materials usage by MassDOT over the last 5 years. We are not certain how this compares to earlier years in terms of tons applied. In the 2012 ESPR, was the tonnage based on NaCl only? If so, then comparing Table 1-3 from the 2012 report with Table 1.4 of the 2017 report indicates the statewide trend may not actually be headed in a downward direction.

- Page ES-2 explains that MassDOT assumed maintenance of approximately 729 lane-miles of Department of Conservation and Recreation (DCR) roads. Assuming salt usage is much lower on these roads than state highways, displaying salt use data only by lane-mile may artificially skew results from 2011 and on to look lower. That is why we are interested in total application by tonnage.

CRC recommendation: MassDOT should present data in a consistent fashion to the 2012 ESPR, and show total application in tons by district and state-wide for the previous 10 or 15 years.

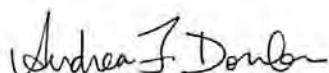
The maps presented in Appendix B show an alarming upward trend of salt concentrations in many of the public water supplies displayed.

We continue to be concerned about chloride trends affecting freshwater streams. In our comments on the workplan, we provided some chloride data in rivers in our watershed from 2014 and 2015. The Deerfield River Watershed Association (DRWA) is conducting a water quality program this summer, sampling about a dozen sites in the Deerfield watershed on a biweekly basis between mid June and the end of August, and all samples are being tested for chloride. We will submit that information when it's available. We hope more water quality data will become available across the state.

Otherwise, it does appear that MassDOT's program to reduce salt application has matured over the last decade, and we hope improvements can continue to be made.

CRC appreciates the opportunity to provide comments. I can be reached at adonlon@ctriver.org or (413) 772-2020 x.205.

Sincerely,



Andrea F. Donlon
River Steward

cc: Kim Groff, MassDEP
Julia Blatt, Massachusetts Rivers Alliance



CITY OF CAMBRIDGE

MASSACHUSETTS
Water Department
250 Fresh Pond Parkway
Cambridge, MA 02138
617 349 4770
fax 617 349 6616



August 23, 2017
by email

Secretary Beaton
Executive Office of Energy and Environmental Affairs (EEA)
Attn: MEPA Office
Alex Strysky, EEA No. 11202
100 Cambridge Street, Suite 900
Boston MA 02114

Re: EEA #11202, MassDOT Snow and Ice Control Program, Draft Environmental Status and Planning Report

Dear Secretary Beaton,

The City of Cambridge Water Department (CWD) appreciates the opportunity to comment on the above referenced draft Environmental Status and Planning Report (ESPR). Cambridge receives its water from a 24 square mile surface water supply watershed located in the municipalities of Lincoln, Lexington, Waltham, and Weston. Two of the City's three reservoirs, Hobbs Brook Reservoir and Stony Brook Reservoir, are adjacent to I-95 and Route 2. Routes 2A, 20 and 117 also cross the Cambridge watershed in the east-west direction. Given the proximity of Cambridge's reservoirs to major roadways maintained by MassDOT, decisions regarding snow and ice control have a direct impact on the Cambridge drinking water supply. In recognition of this impact, MassDOT created Reduced Salt Zones (RSZs) along I-95 and Route 20 (Districts 4 and 6) to help protect the City's drinking water resources.

CWD commends MassDOT for the demonstrated success of the FY2011 policy and equipment changes (Figure 1.5 of the draft ESPR). These efficiency-based changes are both economically and environmentally beneficial. Despite these improvements, the Cambridge drinking water supply remains severely salt impacted, and the Hobbs Brook Reservoir impaired. Extensive water quality monitoring performed by CWD, the United States Geological Survey (USGS), and a 1985 study conducted by CWD and MassDOT (then Massachusetts Department of Public Works) indicate that the salt impairment is predominately attributable to MassDOT deicing activities. Given the

increased MassDOT watershed salt use since the 1985 study was conducted and the concurrent increased salt concentrations in the water supply, CWD requests faster and more aggressive reductions in salt applications and/or alternative mitigation strategies.

Cambridge Source Watershed Impacts

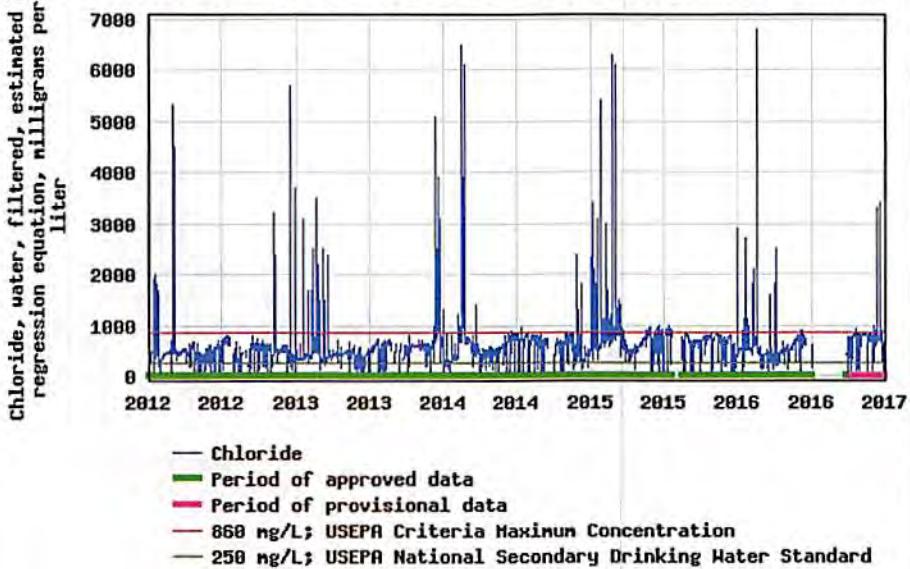
CWD and USGS operate and maintain 12 tributary stage, flow, and water quality stations and 3 reservoir monitoring stations. Two recognized salt-impacted tributaries abutting Rt. 128 (both draining significant highway area) are currently being studied by the USGS and University of Massachusetts (UMass). Past UMass reports from those stations funded under the MassDOT Highway Deicing Agent Remediation Program suggest that a “significant fraction of the deicing agents applied during winter operations infiltrates into groundwater near the drainage system at both stations [USGS gaging stations [01104415](#) and [01104455](#)] and returns to the drainage system as baseflow throughout the year” (Progress Report No. 42, April 2012).

USGS baseflow sampling at station 01104415 between 2012 and 2016 support this claim with an average chloride concentration of **766 mg/L** and a median chloride concentration of **563 mg/L**. Mean and median baseflow chloride concentrations for the same time period at station 01104455 from were also high at **378 mg/L** and **357 mg/L**, respectively. These concentrations are well above the EPA chronic toxicity standard of 230 mg/L and the SMCL of 250 mg/L. Sodium concentrations were also high at these two sites, with mean and median USGS baseflow concentrations for the same time period ranging from **208 mg/L** and **192 mg/L** at 01104455 to **460 mg/L** and **334 mg/L** at 01104415, well above the 20 mg/L drinking water guideline. Spikes in chloride concentrations also occur during winter events as deicing materials wash into the tributaries and can cause acute spikes in chloride which exceed the EPA’s acute toxicity standard of 860 mg/L. A graph of real-time chloride concentrations (estimated from specific conductance) from the 01104415 station demonstrates this phenomena.



USGS

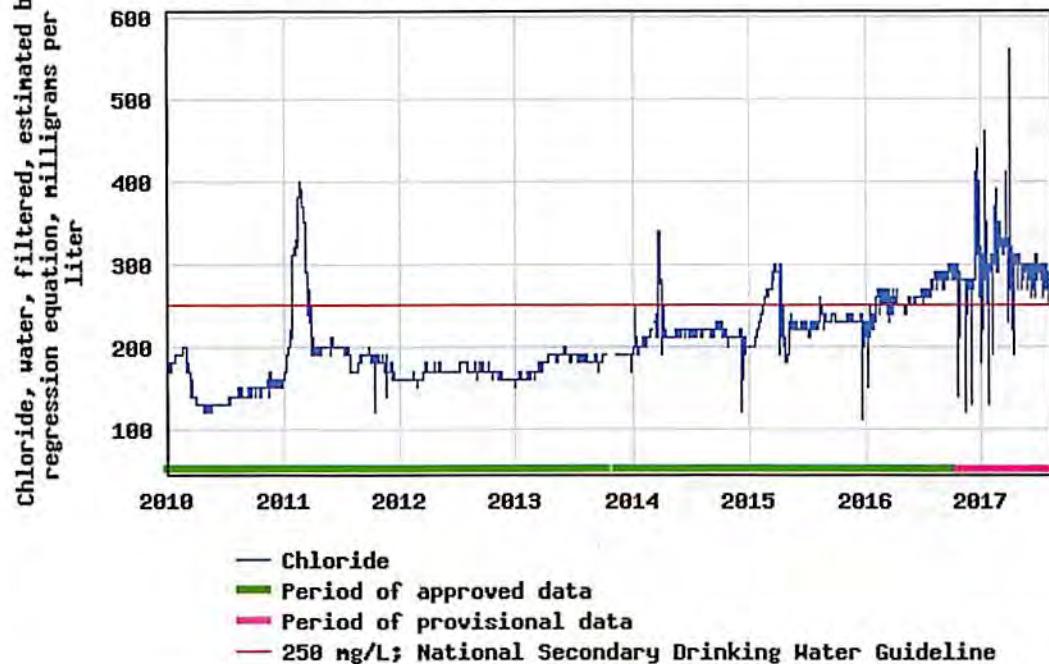
USGS 01104415 CAMBRIDGE RES., UNNAMED TRIB 2, NR LEXINGTON, MA



The Hobbs Brook Reservoir continuous monitoring station 01104430 also shows increasing chloride concentrations, with chloride levels in excess of the 250 mg/L SMCL for almost all of 2016. The chloride levels in 2016 and 2017 were likely elevated due to the drought. However, the trend illustrates the extent to which baseflow to the Hobbs Brook Reservoir is salt impaired.



USGS 01104430 HOBBS BK BELOW CAMBRIDGE RES NR KENDALL GREEN, MA



CWD baseflow water quality samples also demonstrate severe salt impairment. Figure 1 shows mean annual chloride concentration over time (2000-2016) at CWD's 12 tributary monitoring sites. The sites with greater than 95 percent of the drainage area within 0.5 miles of a MassDOT roadway (Route 2, 20, 117, or I-95) regularly exceed the chloride SMCL and EPA chronic toxicity standard.

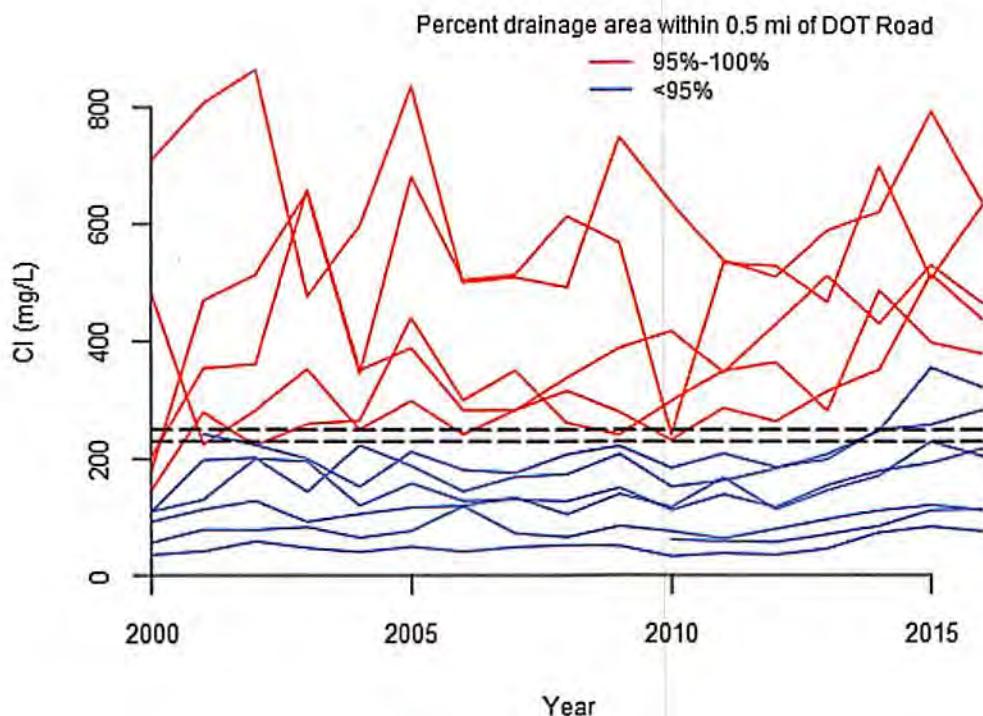


Figure 1. Mean Annual Baseflow Chloride Concentrations at 12 CWD Tributary Monitoring Sites, 2000-2016.
 Dashed black lines represent the 250 mg/L chloride SMCL and the 230 mg/L EPA chronic toxicity standard.

Weekly chloride samples from CWD reservoirs do not typically exceed the chloride SMCL. However, drought conditions in 2016 caused chloride concentrations in the Hobbs Brook Reservoir to exceed the SMCL in 91 percent of samples. During the summer and fall, Hobbs Brook Reservoir supplements flows to the Stony Brook Reservoir and Fresh Pond Reservoir. During the 2016 drought, extended and increased reliance on water released from Hobbs Brook Reservoir resulted in 29 percent of weekly chloride samples at Stony Brook Reservoir exceeding the SMCL. By October 2016, chloride concentrations in Fresh Pond Reservoir, the terminal reservoir in the Cambridge water system, had also exceeded the chloride SMCL. As the 2016 drought demonstrated, salt impairments at the Hobbs Brook Reservoir have a cascading effect on water quality throughout the entire Cambridge water supply system. In addition to chloride, all CWD tributary and reservoir sampling locations regularly exceed the 20 mg/L sodium guideline.

A joint study between MassDOT (then Massachusetts Department of Public Works) and CWD conducted by Geotechnical Engineers, Inc. in 1985 estimated that average annual MassDOT salt applications between 1967 through 1985 to Routes 128, 2, and 2A in the Hobbs Brook Reservoir watershed account for 72% of salt (NaCl) sources. Eight percent of reservoir loading was attributed to spillage and leaching from the then uncovered, pervious MassDOT salt storage depot, 13% from municipal deicing, and the remaining 7% from commercial and residential use. During the same period, average sodium concentrations leaving the Hobbs Brook Reservoir were

43 mg/L and MassDOT sodium chloride applications averaged **1,207 tons** per season. Currently (2012-2016), under MassDOT's reduced salt policy, the average sodium concentration leaving the reservoir is **138 mg/L**. In 2015, data provided to CWD from MassDOT estimated that approximately **3,000 tons** of sodium chloride were spread in the Hobbs Brook Reservoir watershed, plus 18,100 gallons of liquid CaCl_2 or MgCl_2 brine. Despite reductions in salt use by MassDOT since the last ESPR, salt application tonnages still correspond to roughly a **three-fold increase** since the 1985 study.

The City of Cambridge would like to again partner with MassDOT to revisit the 1985 Sodium Study, incorporate chloride into the scope of the study, and recreate the comprehensive loading/fate and transport model with current USGS data. This information will help CWD and MassDOT develop reduction strategies that can complement MassDOT's existing strategies to reduce water supply salt concentrations over time.

Reduced Salt Zones

Sections 2.2.2 through 2.2.6 of the 2017 draft ESPR provide an update on existing RSZs. However, the information in this section is overly general. Table 2.1 provides information on the number of RSZs and lane miles, but no information on how salt applications in the RSZs compared to the rest of the state. Section 2.2.2 did not discuss what pilot programs or initiatives, if any, occurred in within each RSZ between 2012 and 2017.

Mixing sodium chloride with sand appeared to be the primary strategy to reduce salt application rates in RSZs, a strategy MassDOT is phasing out due to environmental impacts of sand. Section 2.2.3 explains that in areas with sand blending, the amount of salt applied likely equals the 240 pounds/lane mile used in non-RSZs due to increased application frequency needed to compensate for the reduced salt mix. Section 1.9 mentions a current RSZ pilot program testing a sand-free practice of maintaining lanes with a lower salt application rate, although information was not provided on how many years the pilot program will run before expanding to other RSZs. In Chapter, MassDOT commits to continue reducing sand use in RSZs. However, no information was provided on MassDOT's plan for reducing salt applications below the 240 pounds/lane mile target rate.

CWD urges MassDOT to immediately investigate reducing target application rates below 240 lbs/lane mile in RSZs and develop a program similar to that in Minnesota where rates are adjusted based on weather conditions. The "Minnesota Snow and Ice Control Field Handbook for Snowplow Operators" guidance document seems to indicate that prewetted road salt could be potentially applied at 240 lbs/ **two** lane miles under most cold weather events.

To monitor progress towards achieving the "reduced" objective in the "Reduced Salt Zone" designation, CWD requests that the final 2017 ESPR include a comparison of salt loads in RSZs versus non-RSZs, a list of pilot actions or other actions implemented in RSZs since the 2012 ESPR,

a target application rate below 240 pounds/lane mile for RSZs, and a specific set of actions MassDOT plans to implement to achieve this target.

General Document Comments

In general, the statewide salt reduction plan shows promise in creating efficiencies and lowering deicing material amounts. Based on the large amounts of salt groundwater contamination in watershed highway layouts, and from the Lexington Route 2A Depot, CWD will realize salt impacts for long after chloride-based deicing materials usage is minimized or (however unlikely) eventually phased out. CWD strongly supports the State's allocation of resources to support additional research and the adoption of new technologies to help address this complicated issue.

CWD recommends that MassDOT select a new baseline for measuring progress in reducing salt concentrations based on the 2012-2016 FYs presented in the draft ESPR Figure 1.5. This data reflects the improvements in efficiency gained by MassDOT after FY2011 and will serve as a better baseline for measuring progress moving forward.

Summary of CWD Recommendations for the Final 2017 ESPR

- Partner with CWD to update the "Hobbs Brook Reservoir Sodium Chloride Study" published in 1985.
- Develop a new baseline salt to Winter Severity Index (WSI) relationship for the 2017 ESPR. This new baseline should use data collected after FY2011 since this period accounts for MassDOT's policy and equipment changes.
- Develop a target application salt rate below 240 pounds/lane mile to achieve a reduced salt load in the RSZs.
- Provide information on the specific pilot programs or unique strategies employed in RSZs from 2012-2017 and planned actions for the 2017 ESPR.
- Continue to standardize and improve ways to account for and quantify materials usage on a per event basis and watershed spatial scale. Improving data accuracy, its interpretation and analysis can lead to both short and long term improvements in efficiency and chemical reductions. Accurate information is critical to develop mass-balance impact models. CWD would like to receive reports on a per event basis in addition to annual summaries.
- Operator error is common under long, harsh winter storm conditions and the Cambridge Watershed routes have District overlap plus five interchanges. Geo-fencing and other automating technologies are necessary and should be piloted in the Cambridge source watershed to reduce redundant applications, especially on interchanges and overlap zones.

- Institute a policy that prohibits snow storage in rotaries trucked in from outside a RSZ watershed.
- To reduce groundwater infiltration/salt impacts in highway shoulders, after particularly bad winters and investigate the environmental benefit of physically removing snow banks which are a major source of road salt and other highway-related pollutant contaminants.
- Institute an aggressive public outreach and education campaign to limit driver speed expectations during inclement weather in RSZs. Increase real-time, "reduce-speed" electric signage and enforcement of speed restrictions in RSZs. Violation fines could help offset program costs.
- Review vehicle washing procedures at the Route 2A Lexington, MA depot.
- Reinvestigate potential benefits from installing snow fencing in highway sections crossing and/or abutting the Stony Brook and Hobbs Brook Reservoirs.

Sincerely,



Jamie O'Connell

Watershed Protection Supervisor, City of Cambridge

joconnell@cambridgema.gov

617-349-4781



WalkBoston

August 9, 2017

Secretary Matthew Beaton
Executive Office of Environmental Affairs, MEPA Office
Attn: Alex Strysky
100 Cambridge Street, Suite 900
Boston, MA 02114

RE: Comments on MassDOT Snow and Ice Control Program 2017 Environmental Status and Planning Report EEA# 11202

Dear Secretary Beaton:

WalkBoston appreciates the opportunity to comment on the Snow and Ice Control Program of MassDOT. We are commenting because pedestrian issues are not addressed in the Report. We provided similar comments in 2006, to the then Mass Highway Department.

While MassDOT has made significant strides to incorporate the needs of pedestrians into many of their project designs and safety programs, we are disappointed that the important accessibility, safety and mobility issues that un-shoveled sidewalks, crosswalks and safety islands pose for pedestrians has still not been addressed in this document.

The Report covers many of the steps that the MassDOT will take to deal with the impacts of its application of chemicals on roadways. It discusses in detail the impacts that these materials have on pavement and the relative degree of effectiveness that the materials exhibit when removing snow and ice. It describes procedures that snow plow operators (whether state employees or service-providers hired by the state) must follow, along with ways that the state will oversee the operations associated with snow plowing. In several of these discussions MassDOT comes tantalizingly close to describing potential impacts on pedestrian movement, yet there is no explicit acknowledgement that pedestrians have a stake in the way the state removes ice and snow from roadways and to the relationship between roadway and sidewalk snow and ice clearance. The only mention of pedestrians in the document is where MassDOT indicates that DCR has retained responsibility for sidewalks adjacent to a number of roadways where MassDOT has assumed responsibility for the vehicular travel way and that the MBTA has a plan for its facilities.

The impact of roadway snow and ice clearance on pedestrians

Pedestrians are clearly affected by the removal of snow from roadways and sidewalks and the effects of inadequate clearance that results in unsafe conditions for walking. After a snowfall in Massachusetts, it is possible to view city or town streets where the roadways are well plowed, but the sidewalks are impassable. Common public services such as postal deliveries or meals on wheels can be disrupted. Commuters and school children find their routes blocked. Un-cleared sidewalks parallel to snow mounds can force pedestrians onto the street where pedestrian-automobile crashes are far more likely to occur. Even where sidewalks are cleared, pedestrian access at intersections is frequently blocked by roadway-related snow mounds that impede safe

walking through the intersection and un-cleared snow mounds can prevent pedestrians and drivers from seeing each other clearly at intersection approaches.

The simple activity of walking is dramatically altered by the presence of snow. Snow mounds present a physical challenge to pedestrians, and walkers who are trying to cross mounds of snow to get to a safe walking route may have their attention diverted away from oncoming traffic. Intersections clogged with snow or snowmelt can challenge pedestrians trying to cross, again causing temporary diversion of attention from oncoming traffic. Drivers may not be able to see pedestrians forced onto roadways.

Sidewalks are found along many state roads throughout the Commonwealth, and some roads that were originally constructed without sidewalks now have them as a result of the continuing urbanization and suburbanization of the state. Adding sidewalks is now required for state roads as they are rebuilt and they are thus a standard element of the MassDOT roadway network.

The importance of providing safe pedestrian access in all seasons cannot be taken lightly. It is a matter of public safety, adequate transportation, social justice (many of our citizens who are pedestrian and transit-dependent are lower income or elderly), and economic well being (we discourage elders and the disabled from staying in Massachusetts if they feel isolated and home-bound by wintry conditions).

The lack of sidewalk guidance does not seem to conform to the MHD Project Development and Design Guide, 2006 edition, which states: "MassHighway, in its role as steward of our roadways, must consider a broad range of factors in maintaining (emphasis added) or improving this system, including:

- Safety for all users
- Functionality – the need for access and mobility
- Accessibility for people with disabilities...
- Input and participation from local constituents ..."

The manual quotes state law: "Chapter 87 of the Acts of 1996 requires MassHighway to 'make all reasonable provisions for the accommodation of bicycle and pedestrian traffic...'" (Section 1.2.1, p. 1-3) The manual continues with this Guiding Principle: "Multimodal consideration – to ensure that the safety and mobility of all users of the transportation system (pedestrians, bicyclists and drivers) are considered equally through all phases of a project so that even the most vulnerable (e.g., children and the elderly) can feel and be safe within the public right of way...." Section 1.2 Guiding Principles of the Guidebook, detailed in Section 1.2.1, p. 1-3.

Citing MassDOT's 2017 policies as reflected on the current website, "MassDOT is updating the Massachusetts Pedestrian Transportation Plan to improve conditions for walking throughout the Commonwealth." One of the core goals noted is to "Identify policies and model practices to improve maintenance, year-round usability and state of good repair of existing and planned pedestrian infrastructure."

We urge MEPA to require MassDOT to explicitly incorporate policies and practices related to sidewalk, curb ramp and crossing island snow clearance in its Snow and Ice Control Program.

The Program should address the issues noted below (much of the text is copied largely verbatim from WalkBoston's 2006 comment letter).

Safety for both drivers and pedestrians

The state has determined that highway safety and vehicle mobility are high priority reasons for snow and ice removal. Clearing only the road is insufficient as a method for providing safety. Pedestrians crossing roadways or walking within the roadway constitute significant dangers for both drivers and themselves. The extent to which pedestrians use roadway pavements for walking is greatly expanded when sidewalks are left un-cleared or when roadside snow mounds force people to clamber over them to cross streets. Many miles of MHD (now MassDOT in each instance below) roadways are paralleled by sidewalks and are thus critical components of the pedestrian (and transit) transportation networks.

Development of a protocol for determining who will be responsible for sidewalk snow clearance on MassDOT roadways

Sidewalk clearance responsibilities may well fall to several different parties including MassDOT, local municipalities, other state or local agencies, or private abutters. In order to "ensure the safety and mobility of all users of the transportation system," this responsibility must be assigned, managed and enforced throughout the state. As the owner and operator of this transportation network, MHD should assume the job of leading the effort to determine how and by whom the sidewalks will be cleared.

The right of way as a basis for snow and ice removal

Municipalities throughout Massachusetts remove snow and ice from local roadways and establish methods for removing snow and ice from sidewalks. Yet the state does not take on the same responsibility for its roadways. Thus, local jurisdictions must provide for snow and ice removal from sidewalks along state roadways without substantial state assistance. Without coordination between the state and the municipalities, several issues emerge:

1. **Intersections.** The maintenance of a safe pedestrian passageway is critical at street crossings. The crossings are often blocked by snow plowing procedures that simply pile up snow evenly along the road, covering sidewalks, handicapped ramps and street corners, and forcing pedestrians to walk in the roadways. The responsibilities of the state and its agents in clearing intersections – including pedestrian access through the intersection – should be spelled out. Attention to this issue can help municipalities cope with comprehensive snow removal for sidewalks.
2. **Roadway use by walkers.** When the state or its agents clear roadways of snow, safe pedestrian passage must be maintained. If the roadway is temporarily used as a substitute sidewalk because sidewalks have not been cleared pedestrian and vehicular safety is compromised. Snow removal frequently results in substantial mounds of snow paralleling the state highway that, in many cases, block the sidewalks and driveways connected to the roadway. Snow mounding as a method of disposal may exacerbate the problem of clearing sidewalks because of the sheer volume of the snow plowed onto the sidewalks.
3. **Planning.** Streets can be designed to make plowing easier. Sidewalks might be placed at a distance from the roadway that is sufficient to accommodate snow plowed from the street. Snow fences could be located to control snow buildup on pedestrian facilities and help reduce

- removal costs. The state should establish guidelines for improved design. Pedestrian safety islands should be designed to remain snow-free after plowing operations.
- 4. **Research.** The Report contains documentation of lane-miles plowed under state responsibility. Perhaps research is necessary to document pedestrian miles on sidewalks along state highways and to show how state snow plowing policies affect pedestrians and how those policies need to be amended or supplemented. In addition to providing a plan for ensuring the clearance of sidewalks, It would be useful to know what financial and technical assistance the state might provide for communities and pedestrians during snowy conditions along state roads through a variety of funding sources such as CMAQ, safety funds or hazard elimination funds.

Coordination of local and state efforts

The method by which state and local coordination takes place is described briefly in the 2006 GEIR. This issue has not been addressed in the 2017 report, but remains an important issue for pedestrian safety.

1. **Division of responsibilities.** As noted above, MassDOT should determine sidewalk snow-clearing responsibilities and how state, local and private entities will divide the work. A detailed plan for coordination is essential to determine precisely how the responsibilities will be divided, especially at locations where different responsibilities will abut or overlap. For example, at intersections where there are sidewalk connections into intersections, pedestrian crossings through intersections, and sidewalks along the roadways and across driveways. It is important for MassDOT to include information about pedestrian issues for inclusion in the plow route schedule each fall and for information to be disseminated by the MassDOT Districts.
2. **Sidewalk snow removal procedures.** Written procedures can help clarify how snow is to be removed from sidewalks along state roads by agents other than the MassDOT. The state, municipalities or other state agencies can establish priority sidewalks that must be maintained for walkers right from the start of a snow emergency. One model has been prepared by the DCR, which works with the MassDOT to clear certain of its roadways. The state clears curb-to-curb, and the DCR clears the sidewalks according to a predetermined priority rating assigned to each sidewalk. Some communities (e.g. Concord) clear snow from sidewalks along state roads according to a plan that has been developed in conjunction with the school department to facilitate safe access to schools. Priorities may need to be established for sidewalks leading to schools, transit, hospitals and clinics, business concentrations, and public services such as police and fire stations, as well as based on the density of pedestrian use.
3. **Bartering.** A bartering process was described in the 2006 GEIR (Section 2.5.3, p. 29) as an informal method of coordinating operations, with the state taking on some municipal responsibilities. This method of coordination could be used to establish procedures for local communities. Coordination might be embedded in written agreements between the state and the cities and towns that define responsibilities for the details of snow removal. This process is no longer included in the Guide and we are curious how it has been replaced.
4. **Communication with the public.** The public should be informed of policy decisions concerning snow removal on sidewalks, streets and at intersections, so that individuals can plan routes to work or school or for other purposes. One method is to place information delineating responsibilities on-line so that can be widely distributed. A good example of delineating agency responsibilities for snow removal is laid out in the Department of Conservation and Recreation's website at:

<http://eoaea.maps.arcgis.com/apps/SimpleViewer/index.html?appid=4a64ec9cf8ac4bb5a5bc97e5e443e798> By laying out snow removal intentions, it may be possible to avert tragedies involving pedestrians walking in roadways.

Thank you for the opportunity to comment on the Report. Please feel free to contact us for clarification or additional comments. We would be very pleased to work with MHD on this important issue.

Sincerely,



Wendy Landman
Executive Director

Cc: Stephanie Pollack, MassDOT Secretary
Sam Salfity, Director of SICP Operations
Jonathan Gulliver, Acting Highway Commissioner
Kate Fichter, MassDOT Assistant Secretary for Policy Coordination
Jackie DeWolfe, MassDOT Director of Sustainable Mobility
Pete Sutton, MassDOT Bicycle and Pedestrian Program Coordinator

MassDOT Response to Comments Submitted on the 2017 ESPR Work Plan and contained in the Sept. 1, 2017 EEA Certificate			
STATE AGENCIES			
EOEA # 11202			
Comment Topic	Comment No.	Comment	MassDOT Response
MassDEP Comments – Douglas E. Fine, Assist. Commissioner, Water Resources Bureau, August 25, 2017 letter			
Maintain Sodium and Chloride Levels in Nearby Water Bodies	DEP-01	<p>Sodium (Na) and Chloride (Cl) are the two major chemicals of concern to protect waters and wetlands from the impacts of road salt. The Na threshold for public drinking waters is 20 mg/L and the Cl threshold is 230 mg/L for chronic toxicity to aquatic organisms. The environmental goal of the MassDOT snow and ice removal practices should be to maintain waters and wetland resource areas adjacent to highways below 20 mg/L for Na and 230 mg/L for Cl, during the winter months. MassDEP recommends that the ESPR provide more comprehensive analyses of both Na and Cl data.</p>	<p>Environmental stewardship is an integral goal of the SICP and is the primary reason for MassDOT's continued investment in various technologies and equipment to become much more efficient with road salt. As described in the ESPR, MassDOT has already reduced its salt use substantially and will continue to improve as newer technologies and information become available. However, this trend toward more efficient use must be balanced with the public safety aspects of maintaining reasonably safe roadways.</p> <p>It would be infeasible and impractical to modify SICP operations for every adjacent wetland and water body based on their current Na and/or Cl level, which are highly variable spatially, seasonally and annually as hydrologic conditions change as well as due to influences from other sources. This would also result in unsafe road conditions. (See Response to Comment DEP-03).</p>
DEP be Consulted if Non-Chloride Deicers are to be Used	DEP-02	<p>For non-chloride based deicers and anti-icers (such as acetates), biological oxygen demand (BOD) is of concern, since acetates reduce oxygen in waters and wetlands that support aquatic organisms including fish. MassDOT currently is not reporting that it uses acetates to deice roadways. However, if MassDOT switches to acetates to reduce Na and Cl loading to waters and wetlands, we request that MassDOT consult with MassDEP to determine target BOD limits in waters and wetlands that should not be exceeded during the winter months.</p>	<p>So noted. MassDOT has no plans to switch to non-chloride deicers in the foreseeable future as these deicers have been found to be less effective, are costlier and have the potential for greater environmental impacts in certain water bodies due to the oxygen demand. MassDOT has pilot-tested the use of CMA years ago and found that it did not perform as well as regular road salt.</p>
Statistical Analyses of Na levels in PWS within a 0.5 mile of a MassDOT Road	DEP-03	<p>Regarding data analyses of Na and Cl in Public Water Supplies (PWS) and the interpretation on their association with MassDOT roads (Pages ES-4 and 2-4 to 2-6), MassDEP recommends MassDOT perform enhanced statistical analyses to find out whether or not the higher concentration of sodium or chloride within a 0.5-mile of MassDOT roadway is a result of MassDOT SICP operations. If the concentration value (mg/L, Sodium or Chloride) is used, then a T-test is suggested. If the percentage of reported concentrations within a range is used, then non-parametric statistics are recommended. MassDEP is available to MassDOT for technical consultation on this.</p>	<p>Even though a higher percentage of PWS within a 0.5-mile of a MassDOT road had sodium levels above the guidance levels compared to PWS located farther away, as discussed in Sec. 2.4.3 of the ESPR, the differences were not statistically significantly ($\alpha = 0.05$) based on a Kruskal-Wallis non-parametric test conducted on the reported sodium data for the two PWS populations. The lack of significant difference suggests that other sources and factors may be having a greater influence on sodium levels in PWS. Other sources and factors include use of treatment chemicals, road salt applied by others and the potential influence of nearby brackish waters. See Response to DEP-05 below.</p>
Recommend Pilot Tests to Quantify Na Contributions in Targeted Areas	DEP-04	<p>In order to quantify the Na and Cl contribution directly caused by MassDOT road salt application, more detailed studies on targeted sites are needed. For MassDOT SICP's Planned Future Initiatives, MassDEP recommends that MassDOT do one or multiple pilot studies to quantify the contribution to the targeted site(s) from MassDOT road salt application in terms of loading of sodium and/or chloride. (Pages ES-4 and 2-5).</p>	<p>MassDOT has continued to utilize various technologies to increase salt use efficiency which have resulted in substantial use reductions. In 2018, MassDOT plans to pilot test the use of AVL/GPS technology in certain locations to help track and account material usage on specific road segments. UMASS-Amherst researchers will assist in the pilot testing through an ISA Agreement. MassDOT has also commissioned UMass scientists to perform field monitoring studies in the Town of Auburn and within the Kampoosa Bog.</p>

Evaluate Sodium Levels in PWS within 0.5-mile of MassDOT Road	DEP-05	<p>MassDEP questions the validity of the statement that "In fact, the data suggests that there is no clear correlation or relationship between sodium levels in PWS wells and distance to a MassDOT roadway" (Page 2-6). Figure 2.3 appears to show that it is more likely that within 0.5 mile of a MassDOT roadway, PWS wells have higher sodium concentrations. MassDEP recommends that the model be re-run and statistical analyses be performed in consultation with MassDEP using a more complete dataset including samples beyond a 0.5-mile radius of MassDOT roadways. MassDEP is available to MassDOT for technical consultation on this.</p>	<p>The low correlation coefficient (R^2 value) of 0.015 suggests minimal correlation between average sodium (Na) levels in PWS and distance to a MassDOT road. In other words, the regression analysis indicates that distance to a MassDOT road explains only 1.5% of the variability in Na levels within the various PWS located within 0.5-mile of MassDOT road. The slope of the regression line shown in Figure 2-3 is essentially flat indicating that as distance to a MassDOT increases or decreases there is very little change in sodium levels. As requested, the regression analysis was redone and included the Na data from PWS beyond a 0.5-mile of a MassDOT road and the results showed an even lower correlation coefficient (R^2) value of 0.013 vs. 0.015 when using data from only PWS within a 0.5-mile. See Figures in Attachment 1.</p> <p>Again, the data suggests that other factors and sources influence sodium levels in PWS and distance to a MassDOT roadway is not a good indicator as to whether sodium levels in nearby PWS will be elevated or not</p>
Assess Chloride Levels in Various Deicers	DEP-06	<p>In view of the different chloride-based products being applied to highways including Sodium Chloride, Liquid Magnesium Chloride, and Salt Brine, MassDEP requests that MassDOT use a common metric to assess the total amount of chloride applied to roads, such as total chloride concentration. Without a common metric, it is difficult to judge whether total chloride concentrations are being reduced.</p>	<p>Liquid deicers by their very nature consist of dilute mixtures of deicer material in water and, thus, have much lower chloride content. The deicer content in liquids is generally between 20 and 30 percent. Thus, the amount of deicer applied in each liquid deicer application is generally much lower. Pretreatment applications typically involve applications of 20 to 30 gallons per lane-mi. Depending on deicer type, this generally translates to about 50 to 100 lb. per lane-mi of deicer material per application as compared to the typical 240 lb. per lane-mi with granular road salt. The approx. 1.5 million gallons of MgCl and salt brine used per year contains about 2,500 tons of road salt material, which translates to about 0.5% of the total road salt used on an average annual basis. This lower concentration is also why liquids can only be used under a narrow range of conditions since the amount of material applied with liquid deicers is usually insufficient during heavy snow and cold temperatures.</p>
Additional Statistical Analyses to Demonstrate Road Salt Reductions	DEP-07	<p>Figure 1.5 indicates that recent efficiency measures and equipment upgrades have resulted in reduced road salt use. MassDEP recommends that MassDOT provide analysis of covariance (ACOVA) to determine whether the reductions are statistically significant, especially since road salt use will vary as evidenced by the winter severity index.</p>	<p>Use of a winter severity index (WSI) accounts for the annual variability in winter severity conditions which normalizes the data and allows for a more direct comparison of annual salt use data between pre- and post-implementation periods. In other words, the only major difference between the pre-and post-implementation periods is the application practices and equipment used. This is a well-established procedure used by other state transportation agencies to assess the effectiveness of efficiency measures. It is unclear how an ACOVA would make the result of this comparison of salt usage data between the two periods any more direct or revealing.</p>

Additional Statistical Analyses for Na Levels in Municipal PWS	DEP-08	Given the limited data for each town in Table 2.4 on Page 2-8 and Appendix B, MassDEP requests that MASSDOT run some non-parametric trend analyses, such as Kendall trend analysis, to determine if there are any statistical changes in sodium concentrations. The critical threshold to analyze in the Kendall trend analysis must set to ≤ 0.05 . MassDEP is available to MassDOT for technical consultation on this.	It seems fairly evident which graphs and which municipalities in Appendix B are showing significant increases in sodium levels over time. Performing additional statistical analyses seems unnecessary. It is important to note that sodium levels can fluctuate simply by changes in hydrologic conditions and will be higher in dry years and lower in wet years. Contributions from other sources can also have a major influence. Again, detailed evaluations of the source contributions and hydrogeological factors would be needed to identify the primary cause for any upward trends, which is considered beyond the scope of the MassDOT SICP. See Response to DEP-03 and DEP-05 above.
Mass-Balance Analyses to Assess Multiple Sources	DEP-09	Since the 1990s, sodium concentrations at several public water supplies in Northeastern Mass that receive runoff from MASSDOT highways have doubled. During this period, MassDOT and several municipalities have gone from applying a sand-salt mixture to application of only salt and salt derivatives. While MassDEP has noted the decrease in salt application that MassDOT has achieved through its new deicing practices, MassDEP has not yet observed a decrease in the sodium concentration at the affected public water supplies. MassDEP does not have data to separate out the sodium inputs to these supplies from MassDOT highway runoff, municipal deicing application, private contractor application to parking lots, etc. MassDEP recommends that MassDOT estimate its impact using methods such as those described in Heath and Morse 2013, which analyzed road salt impacts to wellfields in Wilmington located adjacent to Route I-93, including separating road salt applied by MassDOT, the Town of Wilmington, and local contractors.	<p>As discussed above, MassDOT has reduced its average annual salt usage by approximately 24% statewide following the adoption of anti-icing practices compared to what was used prior to FY2011. District 4, which maintains most of the MassDOT roads in the northeast part of the state, has reduced its average annual salt use by over a third or approximately 36% since the 2010/11 winter. The fact that a corresponding decline in Na levels has not been observed in PWS would seem to suggest that other sources aside from MassDOT SICP operations are having a greater influence Na levels in PWS</p> <p>The amount of impervious area has increased dramatically in many areas of the state over the last several decades. The amount of road salt used to treat local roads and commercial parking lots associated with this new impervious area has also likely increased significantly. Changes in annual precipitation totals can also greatly affect concentrations from year to year.</p> <p>See Responses to DEP-03 and DEP-04 as well.</p>
Process for Establishing RSZ's	DEP-10	In MassDEP's May 20, 2016 comment letter to MEPA on the ESPR Work Plan, we had asked that MassDOT evaluate the areas on the Mass Turnpike within Zone II and Zone A designations to see if more Reduced Salt Zones are warranted. MassDEP asked for this because the Mass Turnpike had been incorporated into the MassDOT roadway network after the development of the last ESPR in 2012. MassDEP also asked if the process for RSZ designations had been improved to be made easier for the applicant because of the challenging nature of the application process currently in use. MassDEP recommends that MassDOT address these two issues in the Final ESPR to describe what efforts, if any, have been made to facilitate municipalities' applications and the designation of RSZs to protect public health.	<p>MassDOT considers all written complaints of salt contamination as serious matters. Information on the application process to submit a salt contamination complaint and a request for a RSZ evaluation is described on our website. Requiring the applicant to provide historical water quality data collected is essential to the application review to ensure that the elevated Na and Cl levels are consistent and persistent. MassDOT is currently working with various municipal and private PWS to assist in data collection or developing remedial measures where MassDOT appears to be a major contributor.</p> <p>Moreover, MassDOT prefers to continue expand and enhance its anti-icing practices and upgrade its equipment to further reduce its salt use statewide rather than continue with RSZs attempt to reduce salt in select areas.</p>

Sodium Levels in PWS located on Cape Cod	DEP-11	<p>On page 2-4, it is stated that the sodium data from public water supplies within the Cape Cod region that are near MassDOT roads have relatively low sodium concentrations. This may be due to those wells drilled deeper and screened deeper in the aquifer. The Cape Cod aquifer is much deeper than the rest of the state and therefore is pulling water from greater depths with more sodium-free groundwater mixing from both above and below the well screen. In theory, the contributing groundwater to these deeper wells is made up of a higher percentage of water that is not impacted by road salt. MassDEP recommends that MassDOT evaluate data on the depth of PWS source to better assess the ESPR's finding.</p>	<p>MassDOT agrees that the relatively low Na levels in Cape Cod wells are perhaps due in large part to the deeper screen depth as well as greater dilution that occurs in sandy outwash material. Since the PWS appear to provide acceptable drinking water resources, it is unclear why additional study and analyses would be needed.</p>
Specify Water Quality Testing Thresholds for Establishing RSZ's	DEP-12	<p>Page 2-0 of Section 2.3 (Salt Remediation Program) states the thresholds for additional sampling to be done by MassDOT regarding complaints initiated by private well owners. It does not state anywhere what the thresholds are that would result in additional MassDOT sampling for Public Water Supplies. MassDEP recommends that MassDOT establish thresholds for the evaluation of impacts to Public Water Supplies.</p>	<p>MassDOT's Policy for responding to PWS complaints is outlined in SOP ENV-0130-1-000, which relies on sampling data to help determine whether chloride levels are nearing or exceeding 250 mg/L. The data is also used to evaluate whether MassDOT appears to be the primary source based on site conditions and surrounding land uses. PWS complaints are discussed among the Snow and Ice Material Usage Committee to evaluate current application policies, identify potential remedial actions including changes in operations that could be used to improve water quality. The Committee may also recommend that a mass balance study be conducted to better understand the potential effect that hydrogeologic factors and the surrounding land uses may have on the PWS.</p>
Clarification on MassDEP Sodium Testing Policy for PWS	DEP-13	<p>The statement on Page 2-4 that all Public Water Systems are required to test for sodium in their raw water and treated water is incorrect. It is also incorrect that sodium testing of all individual sources is required if any one of the sources has an elevated sodium level. Public Water Systems that have their own water sources are required in accordance with 310 CMR 22.06A to test for sodium at each entry point to the water distribution system — this location is after any water treatment has been done, and often includes blended water from multiple wells and/or reservoirs. Testing of sodium in raw water is not required by 310 CMR 22.06A, though MassDEP has the regulatory authority under 310 CMR 22.03(2) to require raw water testing if deemed necessary in a particular case.</p>	<p>So noted. The Final ESPR will be modified to reflect this clarification.</p>
Remove Reference to Town of Reading Sodium Levels	DEP-14	<p>Page 2-7 states that sodium levels in the Town of Reading have decreased in recent years. Reading shut down all of its municipal wells in 2006 when it joined the Massachusetts Water Resources Authority. The last data point in the Appendix B graph for Reading was in 2005. Reading is not relevant to the discussion of recent trends in public water supplies, particularly as it relates to deicing practices implemented since 2010. MassDEP suggests that this reference be deleted, and the analysis re-conducted without Reading data.</p>	<p>So noted. The Final ESPR will be modified to reflect this clarification.</p>

Additional Measures to Minimize Na Levels in PWS and include Cambridge Water District Data	DEP-15	The City of Cambridge is not one of the public water systems included in the Section 2.4 evaluation, or Appendix B. Cambridge's reservoirs receive runoff from Rtes. I-95/128 and Rte. 2. The watershed of these reservoirs has long been a Reduced Salting Zone. The sodium level in the Cambridge public water system has continued to rise since the implementation of the current MassDOT deicing practices. The City of Cambridge reservoir system that receives runoff from Routes I-95/128 and Route 2 should be included, and MassDEP recommends that MassDOT revise their data analysis to include the evaluation of sodium data for this source into section 2.4 or Appendix B, because sodium levels continue to rise in a reduced salt zone for a water supply serving a densely-populated area. MassDEP also requests further evaluation of additional measures to address sodium in Public Water Supplies.	The DEP's database of reported sodium and chloride data for PWS, sent to MassDOT in August 2016, had very limited data for the Cambridge Water Supply. Sodium data from only one sampling location at the water treatment facility, named the Cambridge Common (#304900-01S-04S). Average annual sodium levels ranged from 52 to 83 mg/l over a 10-year period with no discernable trends. Upon request additional sodium data was provided by CWD after the Draft ESPR was published. This data showed Na levels in both the raw and finished water at the Fresh Pond intake. This additional data, which is summarized in the Final ESPR, indicated that the average annual Na levels ranged approximately 43.mg/l in 1993 to approximately 105 mg/l in 2016/17. The higher levels in recent years may be in part due to the drought conditions that the region has experienced in the last 2 to 3 years, since 2015.
Evaluate Salt Contributions Due to Hardness treatment	DEP-16	On page 2-10 it is stated that PWS that are adding salt to treat for hardness may represent a significant source of the chloride levels. That may also result in higher sodium levels. Also, some PWS use NaOH instead of KOH for pH adjustment which can also increase the sodium concentration in the source. MassDEP asks that MassDOT evaluate these uses for their contribution to sodium sources, which may affect future control measures.	MassDOT considers this request to analyze the effects of adding treatment chemicals to be outside of the scope of ESPR since any added sodium and chloride contributions resulting from treatment of hardness is unrelated to the Snow and Ice Control Program.
MS4 Stormwater Permit	DEP-17	MassDEP requests that MassDOT integrate its snow and ice control program with its permit obligations specified in the MS4 permit issued jointly by the U.S. EPA and MassDEP, including for stormwater runoff discharged to adjacent waters and wetlands.	MassDOT has provided updates of its SICP activities in the MS4 annual reports submitted to EPA and thus, considers the SICP already integrated into the MS4 permit. MassDOT also submits SICP Annual Reports that provides additional information regarding operations and are published in the Environmental Monitor.
Compliance with Vehicle Washing Policy	DEP-18	MassDOT and its contractors rinse vehicles that are used in road salting to reduce corrosion to those vehicles. Section 1-4 Vehicle Washing Policy: Mass DOT's "strict vehicle washing policy" requires rinse water to be sent to a closed-drain system (i.e., holding tank) or a municipal sanitary sewer system. There are a number of MassDOT's depots that do not have either a rinse water holding tank, nor a connection to the municipal sewer system. MassDEP recommends that MassDOT ensure that all its depots meet the strict vehicle washing policy by a specific date.	MassDOT S.O.P. ENV-01-22-1-000. states that vehicle washing involving the use detergents or power washing equipment must be done indoors at designated locations that have an approved recycling washing unit, sewer connection or holding tank to capture rinse water. Contractors are not allowed to wash vehicles at MassDOT facilities. MassDOT does not plan to install vehicle washing facilities at all facilities as some depots are only to store materials and not maintain vehicles.
Request to Monitor Emerging Technologies	DEP-19	Regarding stormwater BMPs, MassDEP requests that MassDOT continue to monitor emerging BMP technologies used by other states to identify BMPs capable of effectively treating sodium and chloride in stormwater (Section 1-7).	MassDOT routinely consults with transportation colleagues in other states and is a member of the Clear Roads Research Consortium and is very familiar with the various BMPs used elsewhere. MassDOT is not aware of any stormwater BMPs capable of treating or sequestering sodium and chloride in stormwater.
Modify Practices to Reduce Phosphorus Loading	DEP-20	MassDEP requests that MassDOT examine how to modify road salting practices to prevent the export of phosphorus to nutrient impaired waters from "constructed stormwater treatment wetlands" in order to meet Total Maximum Daily Load (TMDL) requirements. Road salt in runoff that is directed to "constructed stormwater treatment wetlands" has encouraged invasive species growth, increasing phosphorus export, lowering water quality.	MassDOT's uses very few, if any, constructed wetlands for stormwater treatment and relies more on retention/detention type BMPs. MassDOT is not aware of any data or studies that suggest invasive species growth increases phosphorus export in constructed wetlands. It would seem invasive vegetation could also provide phosphorus uptake as well. MassDEP should share any data that shows invasive species growth leads to more phosphorus export. MassDOT considers use of winter sand as a much larger issue and has much greater potential to reduce phosphorus loading if it was no longer used.

Additional RSZs where Potential Impact Costs May Exceed Program Costs	DEP-21	Section 2-2 Reduced Salt Zone areas: MassDEP notes that the additional per lane costs in RSZ areas (\$2,000 per lane mile) are somewhat less than the average costs of economic impacts (approximately \$2,320 per lane mile) due to lost or degraded ecosystem services (see page E-6). Since those costs are higher where salt impacts public water supplies, MassDEP asks MassDOT to reconsider its current data requirements for establishing RSZ areas where the cost of impacts exceeds the estimated additional program costs impacts.	As discussed above, MassDOT has had more success in reducing salt use by using anti-icing practices and various equipment upgrades than using a 50:50 sand and salt application mix in RSZ's. As such, MassDOT plans to expand and enhance the anti-icing practices going forward rather than establishing new RSZs, which represents an outdated and less effective approach.
Assess Statewide Instream Chloride Levels via Sampling at each Road Crossing	DEP-22	Regarding impacts on aquatic organisms, in MassDEP's 2016 comment letter to MEPA, MassDEP indicated it would be helpful for "MassDOT to assess where the road salt from State highways is causing streams and wetlands to exceed the National Recommended Water Quality Criteria for chloride for acute and chronic toxicity to aquatic organisms." MassDEP requests that MassDOT identify the specific streams and wetlands located adjacent to MassDOT highways where road salt directed from highways to those streams and wetlands is exceeding the 230 mg/L Chloride threshold established by the National Recommended Water Quality Criteria. Data collections should include evaluations of seasonal variations, including sampling in winter and spring.	MassDOT believes it would be more prudent and cost-effective to focus its resources and attention on enhancing and expanding its current practices to increase its salt use efficiency. Other agencies and organizations are better equipped and more knowledgeable in collecting water quality data throughout the state. Presumably, MassDEP collects water quality data or compiles relevant data collected by others to develop the 303(d) listing of impaired waters. MassDOT is not aware of any other state transportation agency that collects water quality data in every stream or wetland next to its roadway.
No-salt or Limited Salt Areas in Zone II's & Critical Water Resource Areas	DEP-23	MassDEP requests that MassDOT establish no-salt or limited salt areas when roadways pass through Zone II's of subsurface groundwater supplies and critical water resource areas, such as cold-water fisheries.	A no-salt area is not a viable option without creating a major safety risk to the traveling public. This would likely require legislative action to change MassDOT's mandate to maintain reasonably safe roadways and allow the use a "no-salt or limited salt area" on state roads. As discussed above, MassDOT plans to expand and enhance its anti-icing practices and continue to upgrade its application equipment to increase salt use efficiency, which will continue to use salt use statewide. This provides a triple-bottom line outcome with less overall salt used, more consistent road conditions and will eliminate or greatly reduce the use of sand, which imposes other environmental impacts.

Editorial and Typographical Errors	DEP-24	<p>Typographical Errors: MassDEP has identified the following typographical errors:</p> <ul style="list-style-type: none"> a. Page 1-15 should say 17 years instead of 16 in the 1st sentence; 2nd parag. b. A reference is needed for the following statement on Page 1-8: MassDOT's standard road salt application rate is 240 lbs per lane-mile, which is generally considered the minimum needed to prevent snow and ice from bonding to the pavement under a range of temperature and precipitation conditions. c. Page numbers in Section 2 need correcting. d. Page 2-6 reads "The date indicates that many wells located to a MassDOT ... " – "date" should be replaced by "data". e. Page 2-6, the reference to "2.3.3" in the following sentence should be "2.4.3" ("The WPI study authors noted that sodium levels in water supply wells appear to be trending upward, which is discussed in Section 2.3.3 below and depicted... ") f. The 1st sentence, 2nd paragraph on Page 2-22 states, "Smith and Granato (2010) reported that the average sediment and phosphorus concentrations in highway runoff from principal roadways were found to be 3 to 10 higher in winter months compared to that in non-winter months." There is a word missing before "higher" in this sentence. Is this "3 to 10 <i>times</i> higher"? "3 to 10 <i>percent</i> higher"? g. The reference is needed for the last paragraph on Page ES-6 that describes a recent study on reduced or lost ecosystem services provided by adjacent and wetland areas along roadways treated with road salt. 	<ul style="list-style-type: none"> a. So noted. The Final ESPR will be modified to reflect this comment. b. Manual of Best Management Practices for Road Salt Maintenance, Clear Roads Report, May 2015 c. So noted. The Final ESPR will be modified to reflect this comment. d. So noted. The Final ESPR will be modified to reflect this comment. e. So noted. The Final ESPR will be modified to reflect this comment. f. So noted. The missing word is "times" higher. g. The study reference is included in the main body of the text on page 5-11 and specifically pertains to Kelting and Laxson (2010)
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State Agencies (cont.)

Topic	Comment No.	Comment	MassDOT Response
Massachusetts Division of Fisheries & Wildlife, Natural Heritage Bureau, David Paulson, Senior Endangered Species Review Biologist, email to EEA Secretary, August 7, 2017			
	NHB-01	<p>The Natural Heritage & Endangered Species Program (NHESP) of the MA Division of Fisheries & Wildlife (DFW) has reviewed the <i>MassDOT Snow & Ice Control Program 2017 Environmental Status and Planning Report</i>, and the NHESP would like to offer the following comments regarding state-listed rare species and their habitats:</p> <ul style="list-style-type: none"> • We recently reviewed the MassDOT Snow & Ice Control Program 2017 DRAFT ESPR. The NHESP appreciates recognition of the documented effects that road salt has on chemistry and species composition in Kampoosa Bog. In addition, the NHESP recognizes MassDOT's advancements in technology leading to reductions in salt application statewide. 	So noted.
Kampoosa Bog	NHB-02	<p>The NHESP believes that review through the MEPA process of the MassDOT Snow & Ice Control Program 2017 Environmental Status and Planning Report presents a great opportunity for MassDOT and NHESP to continue to meet and discuss Snow & Ice Control BMPs when working in ecologically sensitive areas (i.e. Kampoosa Bog). Further, the Division looks forward to the ongoing reach and monitoring efforts associated with Kampoosa Bog.</p>	So noted.

Regional Agencies

Topic	Comment No.	Comment	MassDOT Response
Connecticut River Conservancy; submitted by Andrea F. Donlon, River Steward, August 11, 2017			
Annual Salt Usage by District	CRC-01	<p>Our primary comment is on the presentation of data to make the case that salt use has been reduced over the years.</p> <ul style="list-style-type: none"> • In the 2012 draft ESPR, Table 1-3 provided a summary of MassDOT annual salt usage for each district from FY 2002-2011. This table presented total tons/year for each district and state-wide for a period of 10 years, including a 10-year average for each district. Figures 1-2 and 1-3 showed salt use in tons and salt use by lane mile for MassDOT by District for fiscal years 2002-2011. The 2017 draft report discussed why certain districts had a higher salt usage amount, but no salt use information was presented by district, or total tons applied statewide. 	The Final ESPR includes salt use data by district in Table 1.8. During the preparation of the Draft ESPR, there was an ongoing discussion and review regarding potential adjustments in lane-mileage for certain districts. This review has been completed.
Annual Salt Usage in Tons and Tons/Ln-mi	CRC-02	<ul style="list-style-type: none"> • In the 2012 draft ESPR, Figure 1-6 showed a comparison of the statewide annual salt usage (in tons) with average monthly WSI values for FY01-FY11. The 2017 draft ESPR, Figure 1.6 added FY12-FY17 but showed the data by tons/lane mile, which differs from the earlier way the data was presented (tons/year). 	The Final ESPR shows the total statewide usage in tons per year but since MassDOT's lane-miles increased by approximately 15% after FY2011, it is not entirely appropriate to compare total tons used from before to that used now. Presenting the data in tons per lane-mile is a more appropriate comparison. Nonetheless, even with the added lane-miles, the average annual salt usage from FY11 to FY17 in tons/yr is still less than the average

			annual usage in the previous 10 years. The average annual winter severity value was about the same between the two periods.
Annual Salt Usage in Tons and Tons/Ln-mi	CRC-03	<ul style="list-style-type: none"> Table 1.4 of the 2017 Draft ESPR shows MassDOT materials usage over the last 5 years. We are not certain how this compares to earlier years in terms of tons applied. In the 2012 ESPR, was the tonnage based on NaCl only? If so, then comparing Table 1-3 from the 2012 report with Table 1.4 of the 2017 report indicates the statewide trend may not actually be headed in a downward direction. 	A new table (Table 1.4) was added into the 2017 Final ESPR, which provides a similar year to year summary of road salt usage (tons/yr) as presented in the 2012 ESPR. Section 1.6.5 and Table 1.8 presents a district by district comparison of annual salt usage in tons/ln-mi as well as annual changes in winter severity values. On a statewide basis, the average annual salt usage has decreased by approximately 21% compared to the average annual usage in the baseline period (2001 to 2010). This is shown in Table 1.8.
The Effect of DCR roads on usage	CRC-04	<ul style="list-style-type: none"> Page ES-2 explains that MassDOT assumed maintenance of approximately 729 lane-miles of Department of Conservation and Recreation (DCR) roads. Assuming salt usage is much lower on these roads than state highways, displaying salt use data only by lane-mile may artificially skew results from 2011 and on to look lower. That is why we are interested in total application by tonnage. 	The number of DCR lane-miles represents a small fraction of the overall number of lane-miles and includes a number of urban parkways in and around the Boston area. The DCR roads are essentially treated in the same manner and thus, including them does not skew the overall per lane mileage usage. Even with the 15% more lane-miles, the average statewide usage in tons/yr over the last 7 years was less than the average statewide usage between 2001 and 2010.
Salt Use Data	CRC-05	<ul style="list-style-type: none"> MassDOT should present data in a consistent fashion to the 2012 ESPR, and show total application in tons by district and state-wide for the previous 10 or 15 years. 	See similar response to Comment CRC-02.
Appendix B- Sodium Levels in Municipal PWS	CRC-06	<ul style="list-style-type: none"> The maps presented in Appendix B show an alarming upward trend of salt concentrations in many of the public water supplies displayed. 	Although several graphs in Appendix B do show upward trends, it remains unclear what are the primary cause(s) for this upward trend. As discussed above, since MassDOT has reduced its salt use over the last 7 years compared to what was used in the previous 10 years, it would seem that sodium levels would also decrease if MassDOT was the primary source of sodium. In the eastern half of the state, in Districts 4 and 5, the average annual salt usage was reduced by 30% or more. However, despite these reductions, Na levels continued to rise in some wells. Concentrations will increase due to lack of rain during drought periods which was the case in 2015 and 2016. It should be noted that in the last twenty (20) years or so, the amount of impervious area in this region has increased substantially due to various commercial developments. Parking lots and secondary roads associated with new development also utilize road salt during winter months.
Chloride Levels in Streams	CRC-07	<p>We continue to be concerned about chloride trends affecting freshwater streams. In our comments on the workplan, we provided some chloride data in rivers in our watershed from 2014 and 2015. The Deerfield River Watershed Association (DRWA) is conducting a water quality program this summer, sampling about a dozen sites in the Deerfield watershed on a biweekly basis between mid-June and the end of August, and all samples are being tested for chloride.</p> <p>We will submit that information when it's available. We hope more water quality data will become available across the state.</p>	MassDOT would be receptive to review and include any relevant water quality data in future ESPRs as it becomes available.
	CRC-08	Otherwise, it does appear that MassDOT's program to reduce salt application has matured over the last decade, and we hope improvements can continue to be made.	So noted. MassDOT has made considerable changes over the last decade and plans to continue to making improvements into the foreseeable future.

Local Agencies (cont.)

Topic	Comment No.	Comment	MassDOT Response
City of Cambridge Water District, Jamie O'Connell, Watershed Protection Supervisor, August 23, 2017 Letter			
Rate of Adopting Mitigation Measures	CWD-01	CWD commends MassDOT for the demonstrated success of the FY2011 policy and equipment changes (Figure 1.5 of the draft ESPR). These efficiency-based changes are both economically and environmentally beneficial. Despite these improvements, the Cambridge drinking water supply remains severely salt impacted, and the Hobbs Brook Reservoir impaired. Extensive water quality monitoring performed by CWD, the United States Geological Survey (USGS), and a 1985 study conducted by CWD and MassDOT (then Massachusetts Department of Public Works) indicate that the salt impairment is predominately attributable to MassDOT deicing activities. Given the increased MassDOT watershed salt use since the 1985 study was conducted and the concurrent increased salt concentrations in the water supply, CWD requests faster and more aggressive reductions in salt applications and/or alternative mitigation strategies.	MassDOT's has aggressively adopted salt reduction measures over the last seven years. District 4, which serves most of the roads in the CWD watershed has been particularly focused on achieving greater salt use efficiency and has reduced in its average annual salt usage on a ton per lane-mile basis by approximately 36% compared to what was used in the early 2000's. Thus, MassDOT's disagrees with the comment's premise that MassDOT's usage has increased because it has actually gone down. Since the time when the 1985 study was done, the extent of MassDOT's road miles has not changed all the much, however, amount of development that occurred in the watershed over the last 30 to 40 years has arguably changed the landscape substantially.
1985 Hobbs Brook Study	CWD-02	Partner with CWD to update the "Hobbs Brook Reservoir Sodium Chloride Study" published in 1985.	MassDOT would be willing to discuss this issue during the annual coordination meeting with CWD and particularly with respect to logistics in updating the 1985 study. However, if the study is going to be updated, it may be best if MassDEP or CWD took the lead on this effort and a larger group of stakeholders from the watershed should be engaged to gain greater potential buy-in or at least awareness of potential solutions. Otherwise, if MassDOT takes the lead on this effort, it may be perceived as being only a MassDOT issue or, worse, biased and thus, the study findings may gain little public or stakeholder support and a full suite of potential effective solutions may be lost, particularly if other land uses are found to be contributors to the elevated levels.
New Baseline to Compare Salt Use	CWD-03	Develop a new baseline salt to Winter Severity Index (WSI) relationship for the 2017 ESPR. This new baseline should use data collected after FY2011 since this period accounts for MassDOT's policy and equipment changes.	MassDOT believes that the post-implementation period should be at least as long as the 10-year baseline period before a new baseline is considered. There has been only seven winter seasons since FY2011 when the anti-icing practices were really started with a major shift in equipment used and policy changes, but the new equipment and practices are still being "fine-tuned", meaning that additional efficiencies and further reductions could still be achieved. After 10 years of post-implementation data, MassDOT could then evaluate whether a new baseline period should be established.
Lower Application Rate	CWD-04	Develop a target application salt rate below 240 pounds/lane mile to achieve a reduced salt load in the RSZs.	MassDOT, particularly in District 4, has been recently experimenting with a target application rate of 200 lbs/lane-mi in a Reduced Salt Zone area instead of using the salt:sand mix. The pilot study has only been done for one winter so far, but has shown some promise when pavement temperatures are above 25 F. However, additional or higher application rates are generally needed during colder temperatures. District 4 plans to continue to experiment with this target rate but initial results suggest that locking into using a lower application rate may not be feasible under all conditions.

Pilot Programs	CWD-05	Provide information on the specific pilot programs or unique strategies employed in RSZs from 2012-2017 and planned actions for the 2017 ESPR.	See Response to Comments above and below. MassDOT has also been exploring the benefits of advanced mobile and stationary pavement friction sensors.
Automate Salt Use Data Collection	CWD-06	Continue to standardize and improve ways to account for and quantify materials usage on a per event basis and watershed spatial scale. Improving data accuracy, its interpretation and analysis can lead to both short and long-term improvements in efficiency and chemical reductions. Accurate information is critical to develop mass-balance impact models. CWD would like to receive reports on a per event basis in addition to annual summaries.	MassDOT has made and continues to make progress in incorporating equipment and technology to collect usage data on a truck and by route basis. The use of AVL/GPS technology was piloted on several trucks in District 1. In this upcoming winter of FY17/18, MassDOT plans to expand the use of this technology in key areas within multiple districts. Ultimately, MassDOT's goal is to have this technology fully operational in all spreader trucks and routes throughout the state by 2022.
Operator Errors	CWD-07	Operator error is common under long, harsh winter storm conditions and the Cambridge Watershed routes have District overlap plus five interchanges. Geofencing and other automating technologies are necessary and should be piloted in the Cambridge source watershed to reduce redundant applications, especially on interchanges and overlap zones.	See Response to Comment above. MassDOT plans to use AVL/GPS technology to avoid any redundant applications and overlaps. Spreader and plow route mapping was also recently updated and reviewed by district personnel to identify any opportunities to modify and be more efficient.
Snow Storage in Infields	CWD-08	Institute a policy that prohibits snow storage in rotaries trucked in from outside a RSZ watershed.	Snow is not stored in the Cambridge Water District watershed area. It was mistakenly done once several years ago, but it was snow collected from within the Reduced Salt Zone, not from outside the area.
Snow Bank Removal	CWD-09	To reduce groundwater infiltration/salt impacts in highway shoulders, after particularly bad winters and investigate the environmental benefit of physically removing snow banks which are a major source of road salt and other highway-related pollutant contaminants.	MassDOT is not aware of any data that indicates that snow banks contain high levels or a major source of road salt at the end of the season. The melt water from snow banks may actually help to dilute salt concentrations. MassDOT would be receptive to reviewing any data that suggests snow banks are a major source of road salt.
Public Outreach on Driver Behavior	CWD-10	Institute an aggressive public outreach and education campaign to limit driver speed expectations during inclement weather in RSZs. Increase real-time, "reduce-speed" electric signage and enforcement of speed restrictions in RSZs. Violation fines could help offset program costs.	MassDOT has installed numerous electronic messaging signs along major roadways throughout the state. Anecdotally, the signs seem to have had some minor changes in driving behavior. However, full-fledged enforcement of speed restrictions during winter storm events requires public safety personnel that might otherwise be busy attending to vehicle accidents or other safety issues. State law does allow State Police to post enforceable speed restrictions on I-90 but this authority does not extend to other interstates. During winter storm events, it can be difficult to enforce speed restrictions by stopping violators along the side of the road, which could even make traffic and driving conditions more hazardous depending on time of day.
Vehicle Washing	CWD-11	Review vehicle washing procedures at the Route 2A Lexington, MA depot.	The Route 2A Lexington facility is equipped with an indoor washing bay that is connected to a municipal sewer. MassDOT's Vehicle Washing Policy prohibits the use of detergents or power washing equipment for outdoor vehicle washing. Rinsing of vehicles outdoors without detergents or power washing equipment is allowed. No contractors are not allowed to wash or rinse vehicles at this facility.
Snow Fences	CWD-12	Reinvestigate potential benefits from installing snow fencing in highway sections crossing and/or abutting the Stony Brook and Hobbs Brook Reservoirs.	MassDOT does not own adequate Right of Way width to install effective snow fences. To be effective, snow fences generally need to be installed several hundred feet from the roadway. The District can discuss with CWD personnel the potential locations or benefits of snow fences at a future annual meeting.

Topic	Comment No.	Comment	MassDOT Response
WalkBoston, Wendy Landman, Executive Director, August 9, 2017 letter			
Responsibilities for Sidewalk Snow Clearance	Walk-01	<p>Sidewalk clearing responsibilities may well fall to several different parties including MassDOT, local municipalities, other state or local agencies, or private abutters. In order to "ensure the safety and mobility of all users of the transportation system, "this responsibility must be assigned, managed and enforced throughout the state. As the owner and operator of this transportation network, MHD ("MassDOT") should assume the job of the leading the effort to determine how and by whom the sidewalks will be cleared.</p>	<p>MassDOT considers this request to be outside of the scope of ESPR, which primarily focuses on the assessment of potential environmental impacts. MassDOT is finalizing a statewide Pedestrian Transportation Plan which will provide guidance on improving pedestrian accessibility with respect to snow and ice clearance. It is understood that WalkBoston has been a key partner in the development of this plan, which is expected to be completed in early part of 2018. The URL to the Massachusetts Transportation Pedestrian Plan's website is:</p> <p>http://www.massdot.state.ma.us/planning/Main/StatewidePlans/PedestrianPlan.aspx</p>
Intersections	Walk-02	<p>The maintenance of a safe pedestrian passageway is critical at street crossings. The crossings are often blocked by snow plowing procedures that simply pile up snow evenly along the road, covering sidewalks, handicapped ramps and street corners, and forcing pedestrians to walk in the roadways. The responsibilities of the state and its agents in clearing intersections-including pedestrian access through the intersection-should be spelled out. Attention to this issue can help municipalities cope with comprehensive snow removal for sidewalks.</p>	<p>The primary responsibility for sidewalk clearing falls on the "owner and operator" of the sidewalk, which is primarily the municipality or the property owner. Through an MOA with DCR, MassDOT's responsibility and authority for snow removal on urban roadways in the Boston area is defined as being from curb to curb. The responsibility and authority for maintaining and clearing sidewalks is retained by either DCR, the municipality and/or property owner. As discussed above, MassDOT is finalizing a statewide Pedestrian Transportation Plan which will provide guidance for municipalities to develop priorities and identify key pedestrian access routes for snow clearing. It is understood that WalkBoston has participated in the Plan development.</p>
Roadway Use by Walkers	Walk-03	<p>When the state or its agents clear roadways of snow, safe pedestrian passage must be maintained. If the roadway is temporarily used as a substitute sidewalk because sidewalks have not been cleared, pedestrian and vehicular safety is compromised. Snow removal frequently results in substantial mounds of snow paralleling the state highway that, in many cases, block the sidewalks and driveways connected to the roadway. Snow mounding as a methods of disposal may exacerbate the problem of clearing sidewalks because of the sheer volume of snow plowed onto the sidewalks.</p>	<p>See Response to Walk-01</p>
Planning	Walk-04	<p>Streets can be designed to make plowing easier. Sidewalks might be placed at a distance from the roadway that is sufficient to accommodate snow plowed from the street. Snow fences could be located to control snow buildup on pedestrian facilities and help reduce removal costs. The state should establish guidelines for improved design. Pedestrian safety islands should be designed to maintain snow-free after plowing operations.</p>	<p>See Response to Walk-01 The 2006 Project Design and Development Guidance Manual does address and encourage the use of separated walkways, shared use and bike lanes, where there is adequate site conditions and available ROW.</p>
Research	Walk-05	<p>The Report contains documentation of lane-miles plowed under state responsibility. Perhaps research is necessary to document pedestrian miles on sidewalks along state highways and to show how state snow plowing policies affect pedestrians and how those policies need to be amended or supplemented. In addition to providing a plan for ensuring the clearance of sidewalks, it would be useful to know what financial and technical assistance the state might provide for communities and pedestrians during snowy conditions along state roads through a variety of funding sources such as CMAQ, safety funds or hazard elimination funds.</p>	<p>See Response to Walk-01</p>

Division of Responsibilities	Walk-06	<p>As noted above, MassDOT should determine sidewalk snow-clearing responsibilities and how state, local and private entities will divide the work. A detailed plan for coordination is essential to determine precisely how the responsibilities will be divided, especially at locations where different responsibilities will abut or overlap. For example, at intersections where there are sidewalk connections into intersections, pedestrian crossings through intersections, and sidewalks along the roadways and across driveways. It is important for MassDOT to include information about pedestrian issues for inclusion in the plow route schedule each fall and for information to be disseminated by the MassDOT Districts.</p>	See Response to Walk-01
Sidewalk Snow Removal Procedures	Walk-07	<p>Written procedures can help clarify how snow is to be removed from sidewalks along state roads by agents other than the MassDOT. The state, municipalities or other state agencies can establish priority sidewalks that must be maintained for walkers right from the start of a snow emergency. One model has been prepared by the OCR, which works with the MassDOT to clear certain of its roadways. The state clears curb-to-curb, and the OCR clears the sidewalks according to a predetermined priority rating assigned to each sidewalk. Some communities (e.g. Concord) clear snow from sidewalks along state roads according to a plan that has been developed in conjunction with the school department to facilitate safe access to schools. Priorities may need to be established for sidewalks leading to schools, transit, hospitals and clinics, business concentrations, and public services such as police and fire stations, as well as based on the density of pedestrian use.</p>	See Response to Walk-01
Bartering	Walk-08	<p>A bartering process was described in the 2006 GEIR (Section 2.5.3, p. 29) as an informal method of coordinating operations, with the state taking on some municipal responsibilities. This method of coordination could be used to establish procedures for local communities. Coordination might be embedded in written agreements between the state and the cities and towns that define responsibilities for the details of snow removal. This process is no longer included in the Guide and we are curious how it has been replaced.</p>	See Response to Walk-01
Communication with the Public	Walk-09	<p>The public should be informed of policy decisions concerning snow removal on sidewalks, streets and at intersections, so that individuals can plan routes to work or school or for other purposes. One method is to place information delineating responsibilities on-line so that can be widely distributed. A good example of delineating agency responsibilities for snow removal is laid out in the Department of Conservation and Recreation's website at: http://eoeea.maps.arcgis.com/apps/SimpleViewer/index.htm</p> <p>By laying out snow removal intentions, it may be possible to avert tragedies involving pedestrians walking in roadways.</p>	See Response to Walk-01

Attachment 1: Supplemental Figures Presenting Regression Analysis Results of Reported Sodium for PWS located within and beyond a 0.5-mile of a MassDOT Roadway

Figure 1.a: Regression Analysis of Average Sodium Conc. (mg/L) in PWS located within 0.5 mile of a MassDOT Road

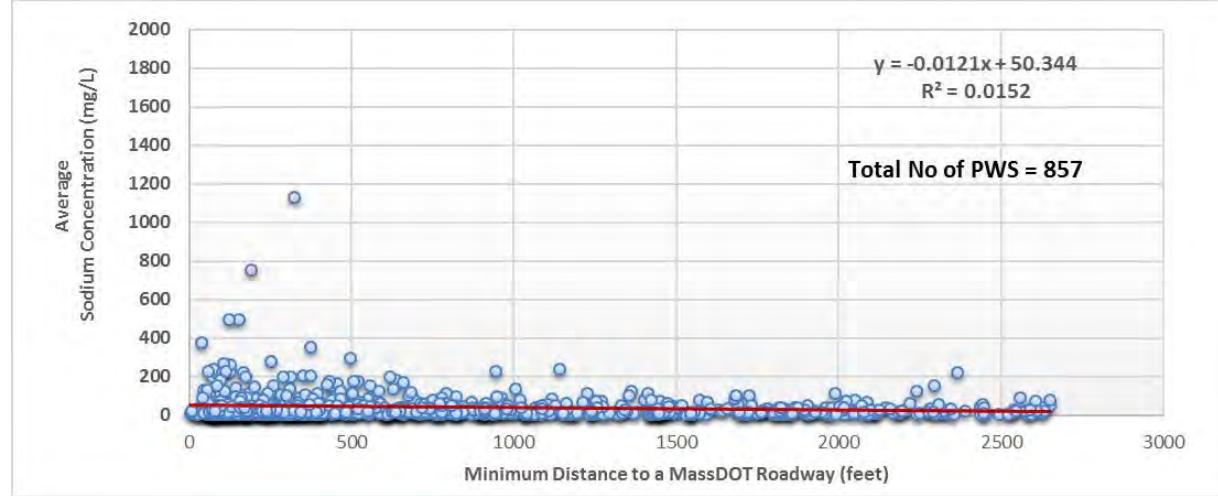
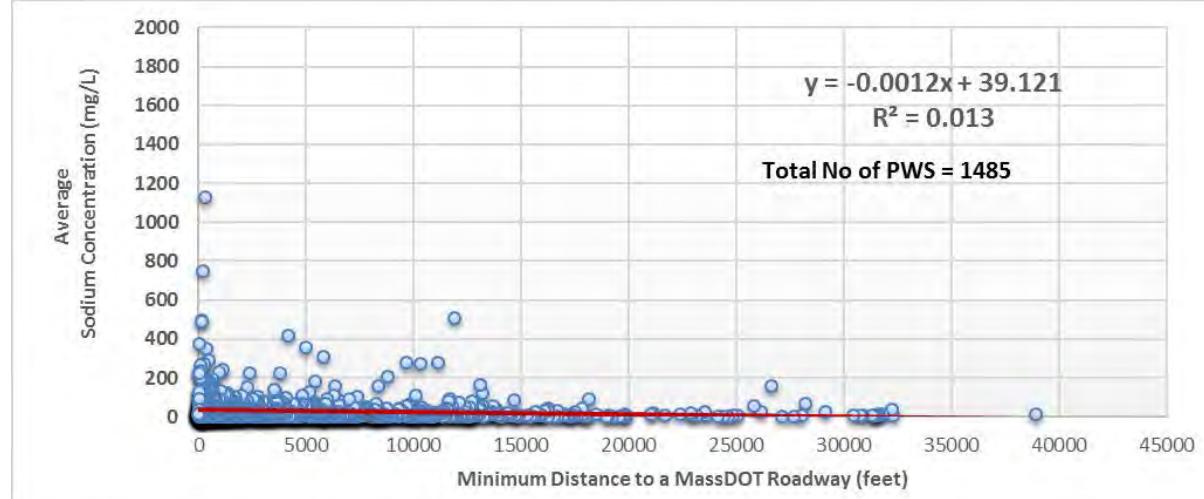


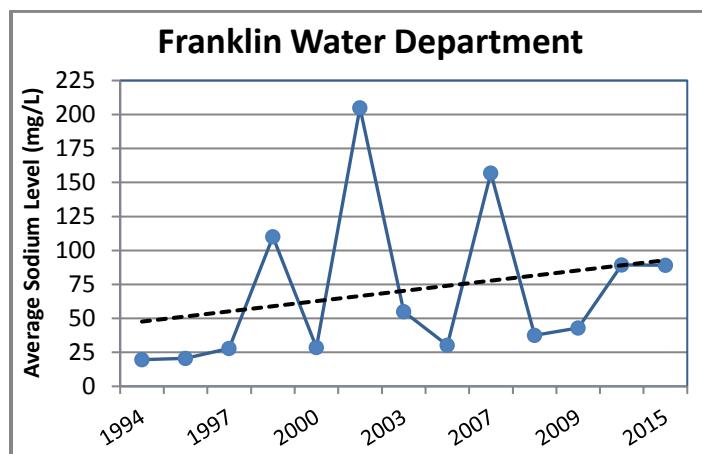
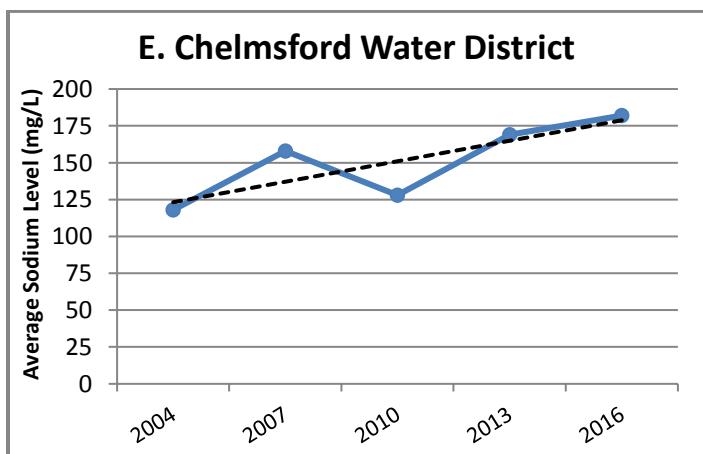
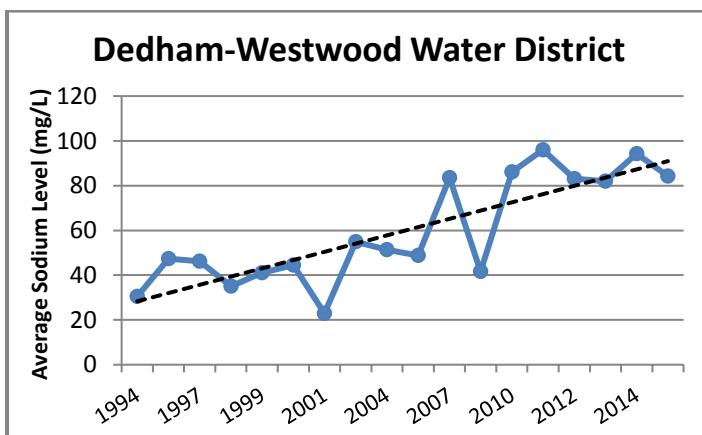
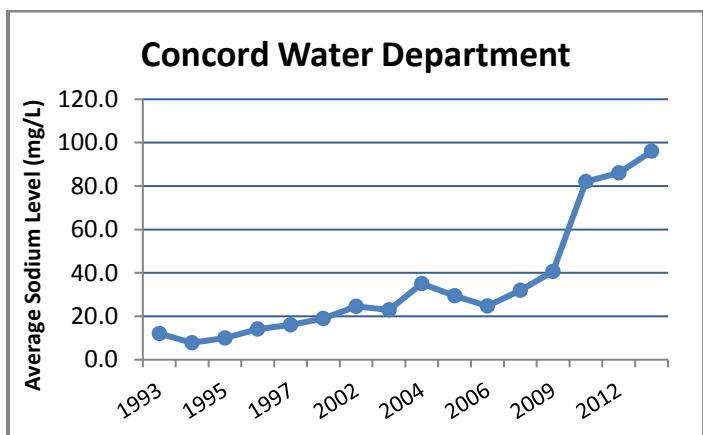
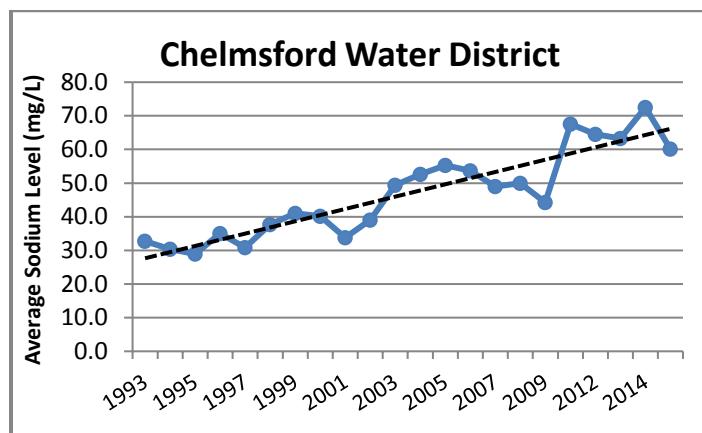
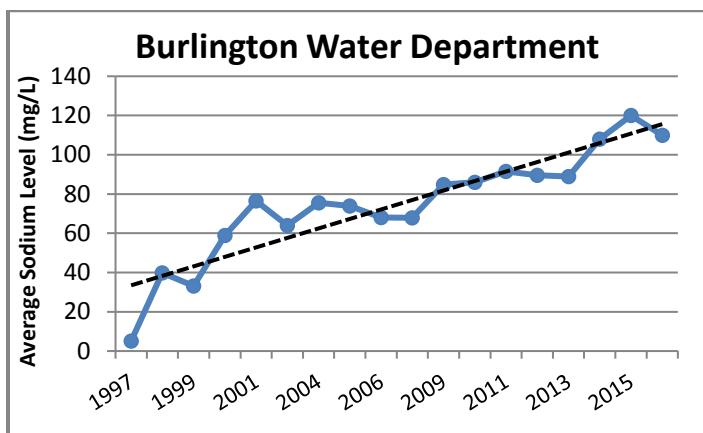
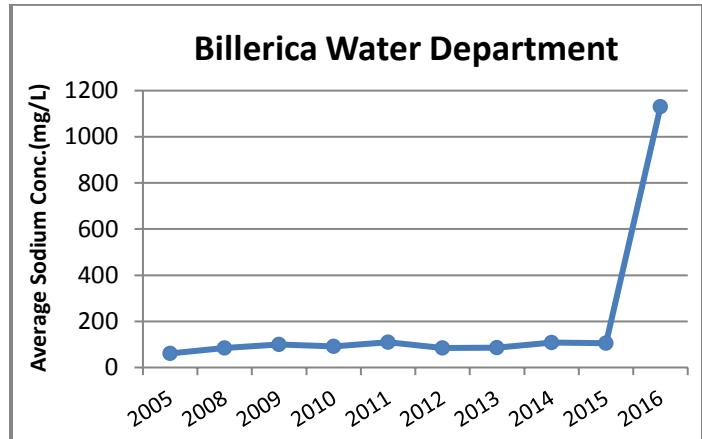
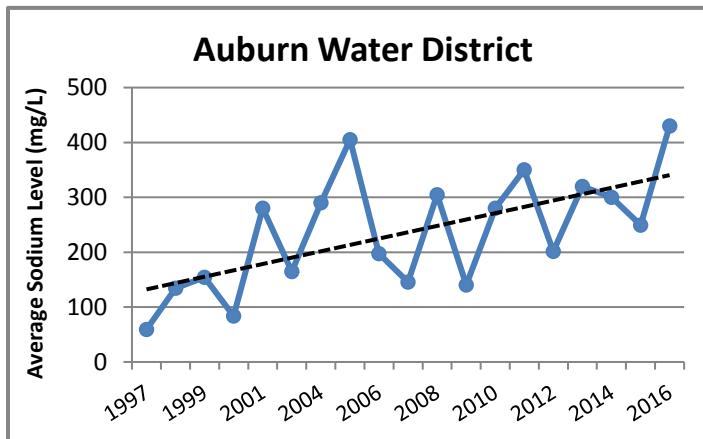
Figure 1.b: Regression Analysis of Average Sodium Conc. (mg/L) in PWS located within and beyond 0.5 mile of a MassDOT Road



Appendix B:

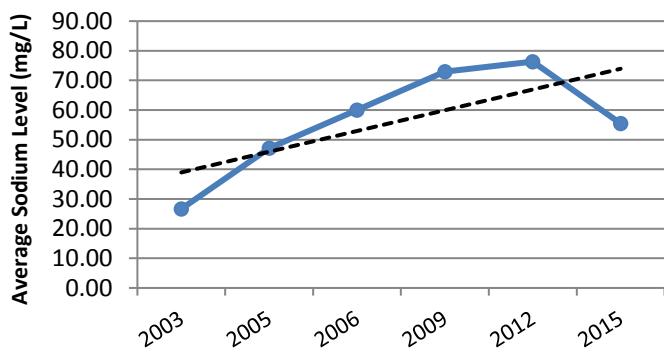
Average Annual Sodium Data Graphs for Various Municipal Public Water Supplies

Appendix B – Graphs for Selected Municipal PWS'

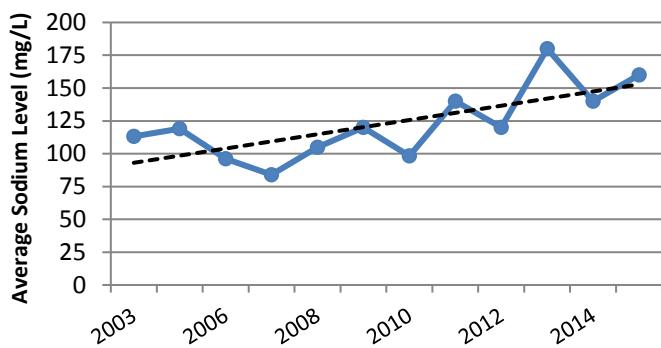


Appendix B – Graphs for Selected Municipal PWS'

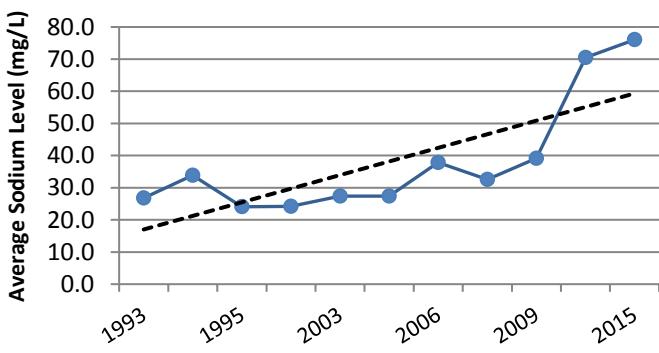
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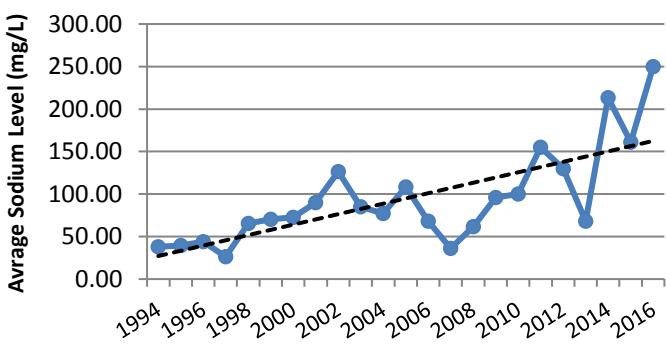
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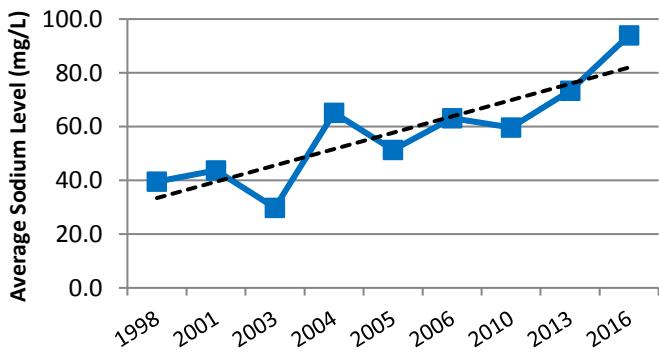
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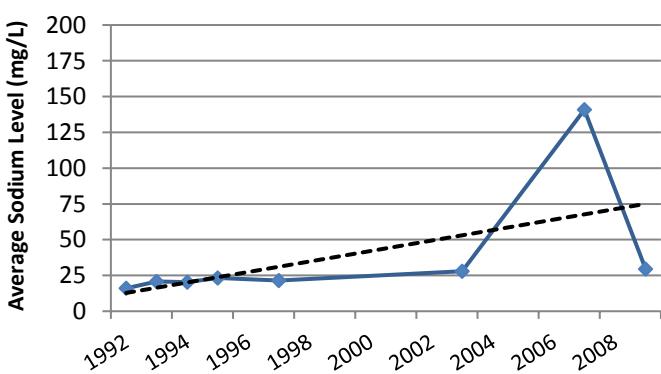
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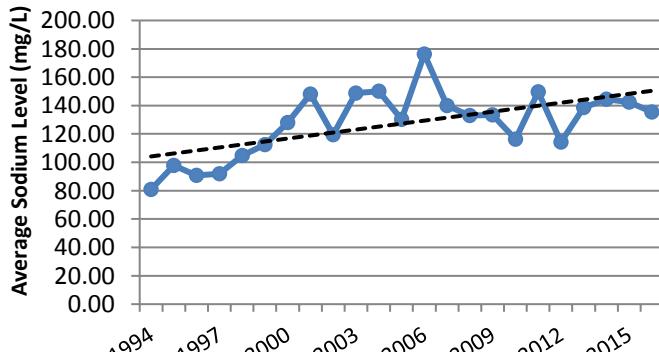
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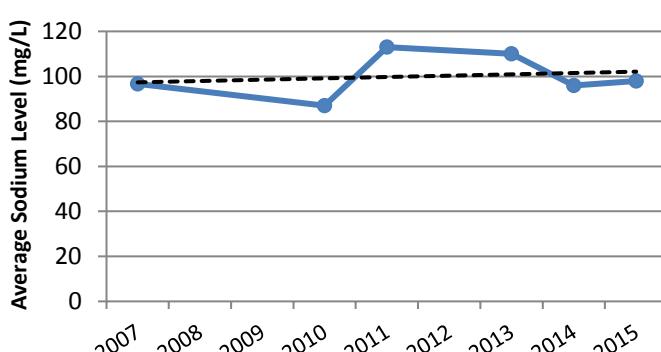
N. Attleboro Water Dept



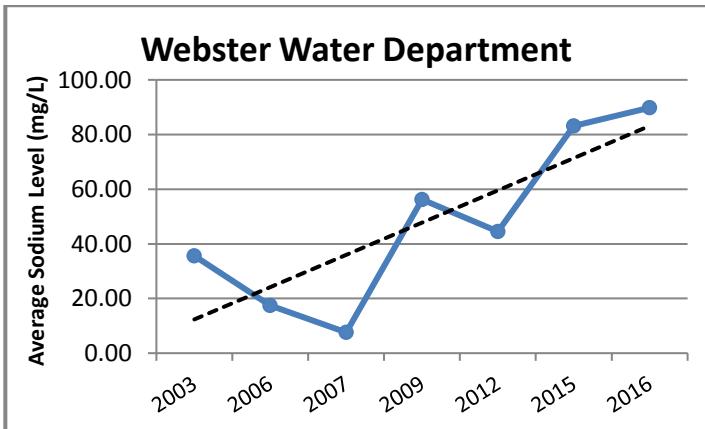
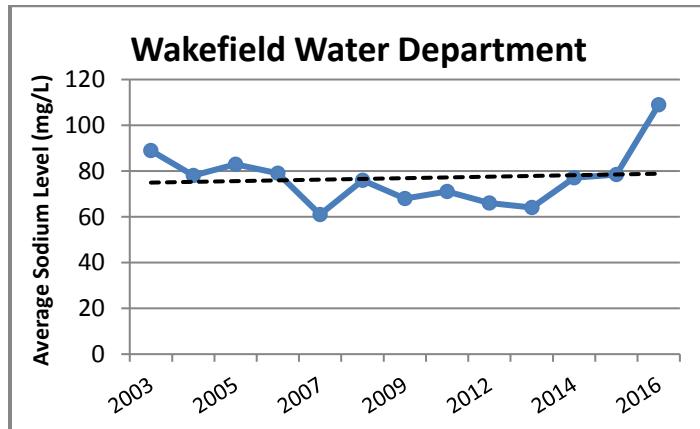
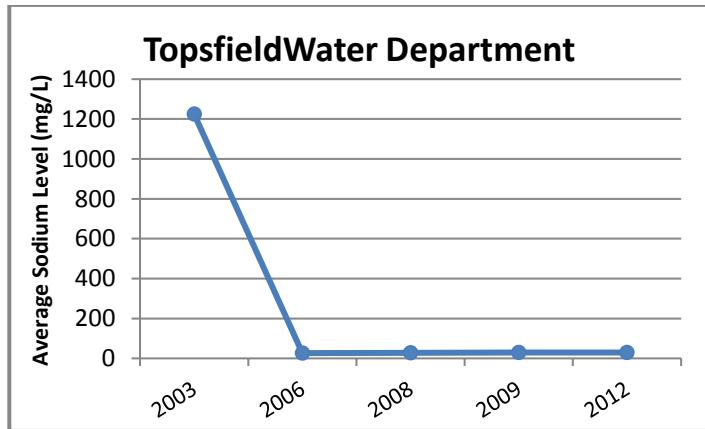
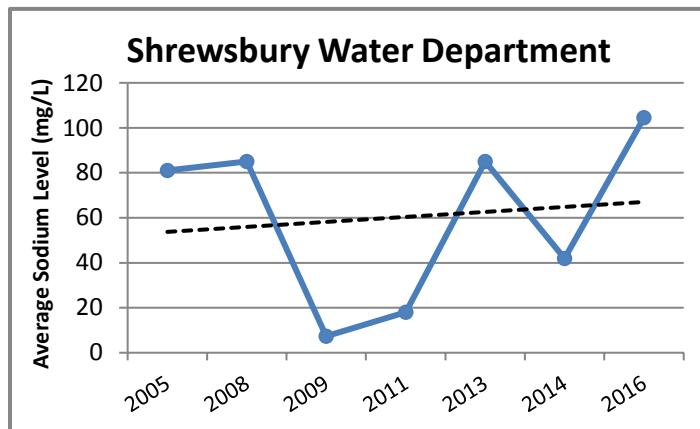
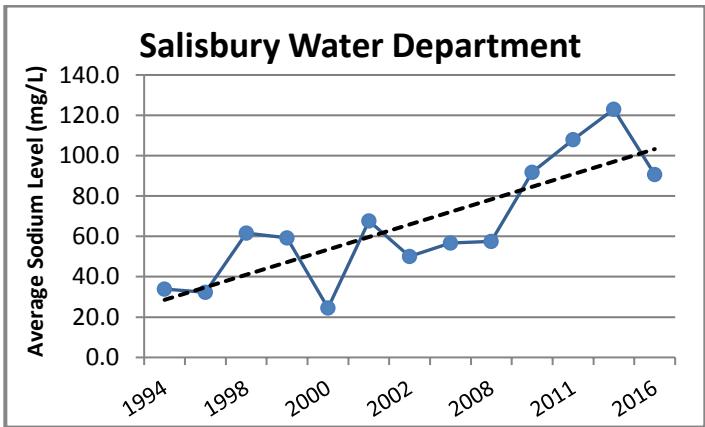
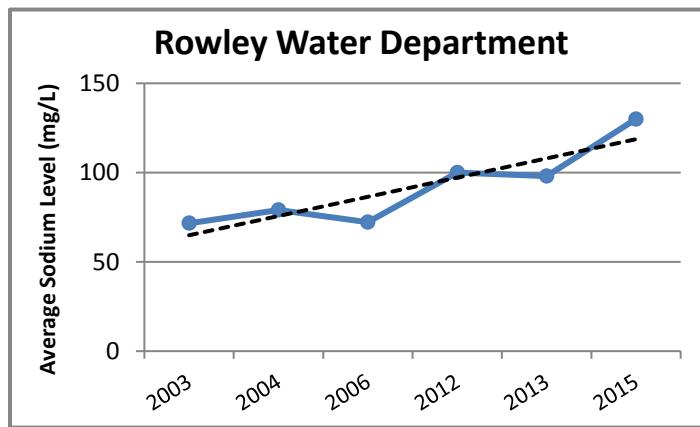
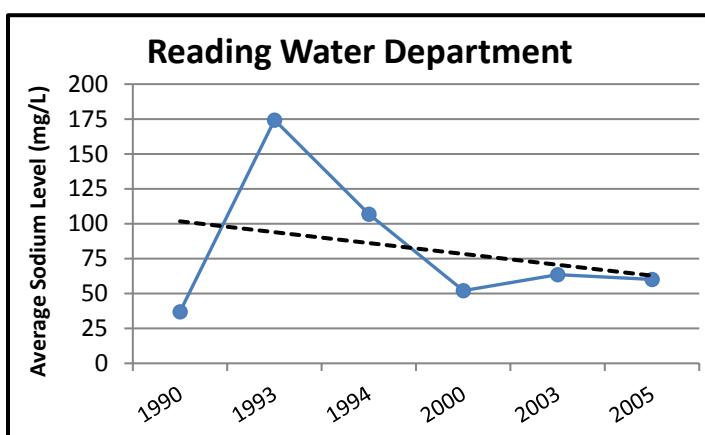
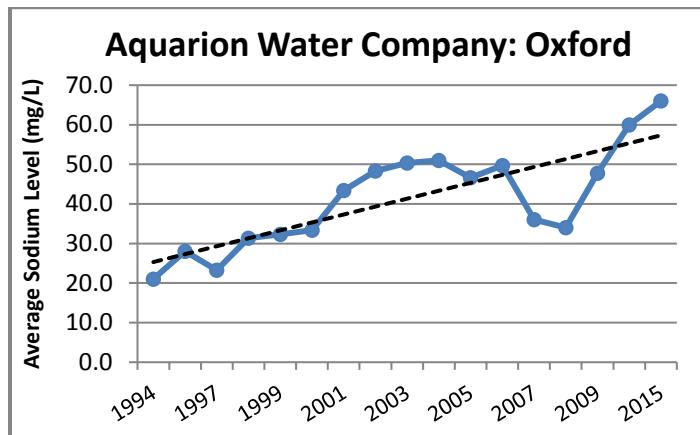
North Chelmsford Water District



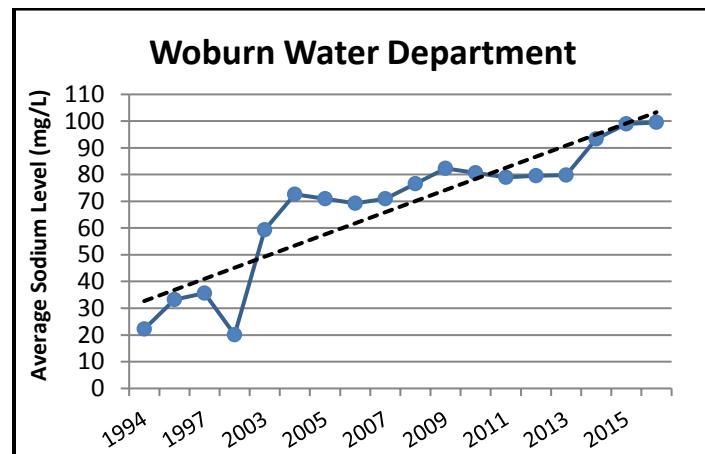
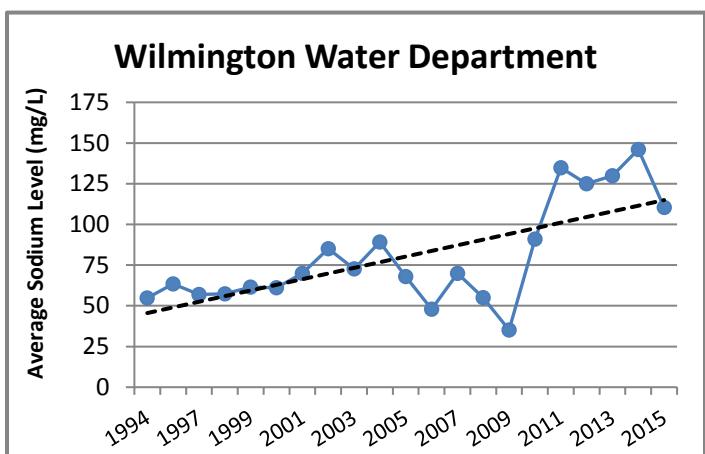
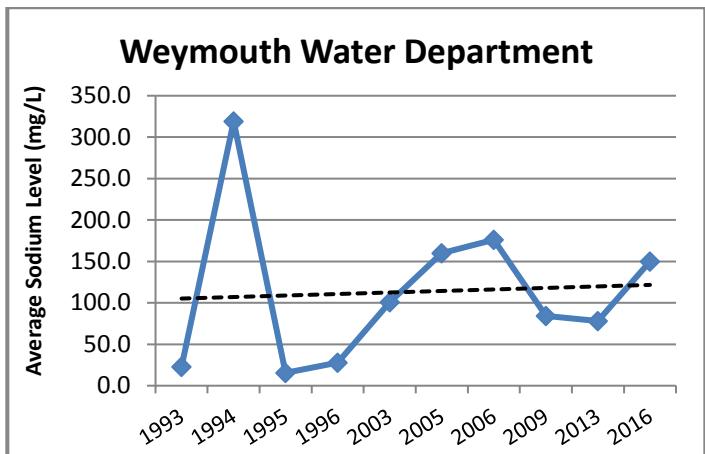
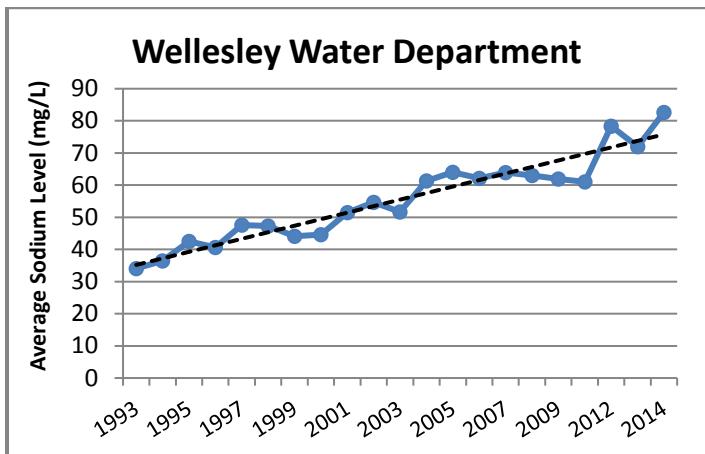
Orange Water Department



Appendix B – Graphs for Selected Municipal PWS'

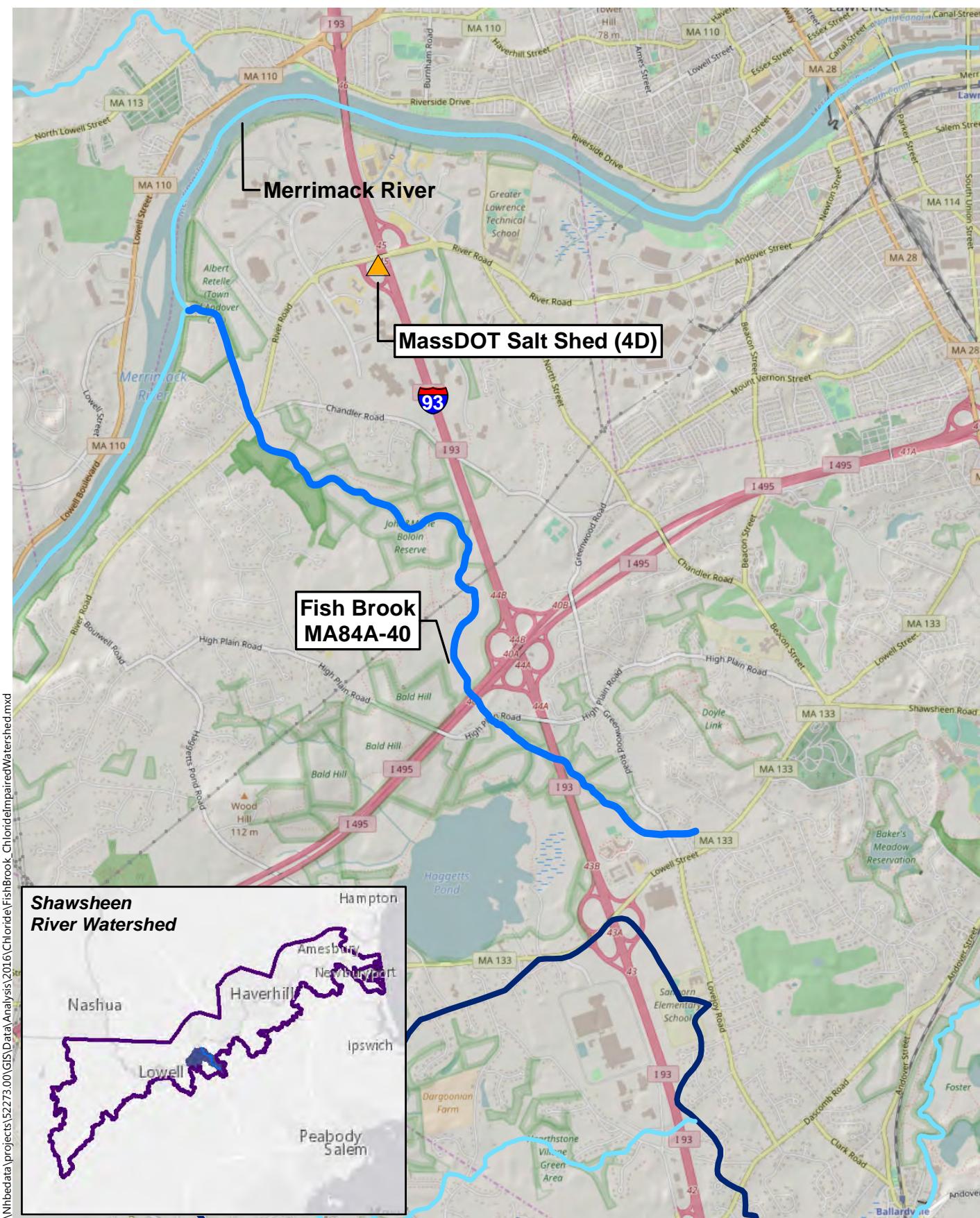


Appendix B – Graphs for Selected Municipal PWS'



Appendix C:

Watershed Maps of Chloride Impaired Waters



↑ 0 1050 2100 4200 Feet

2017 Snow & Ice Control ESPR

MassDOT

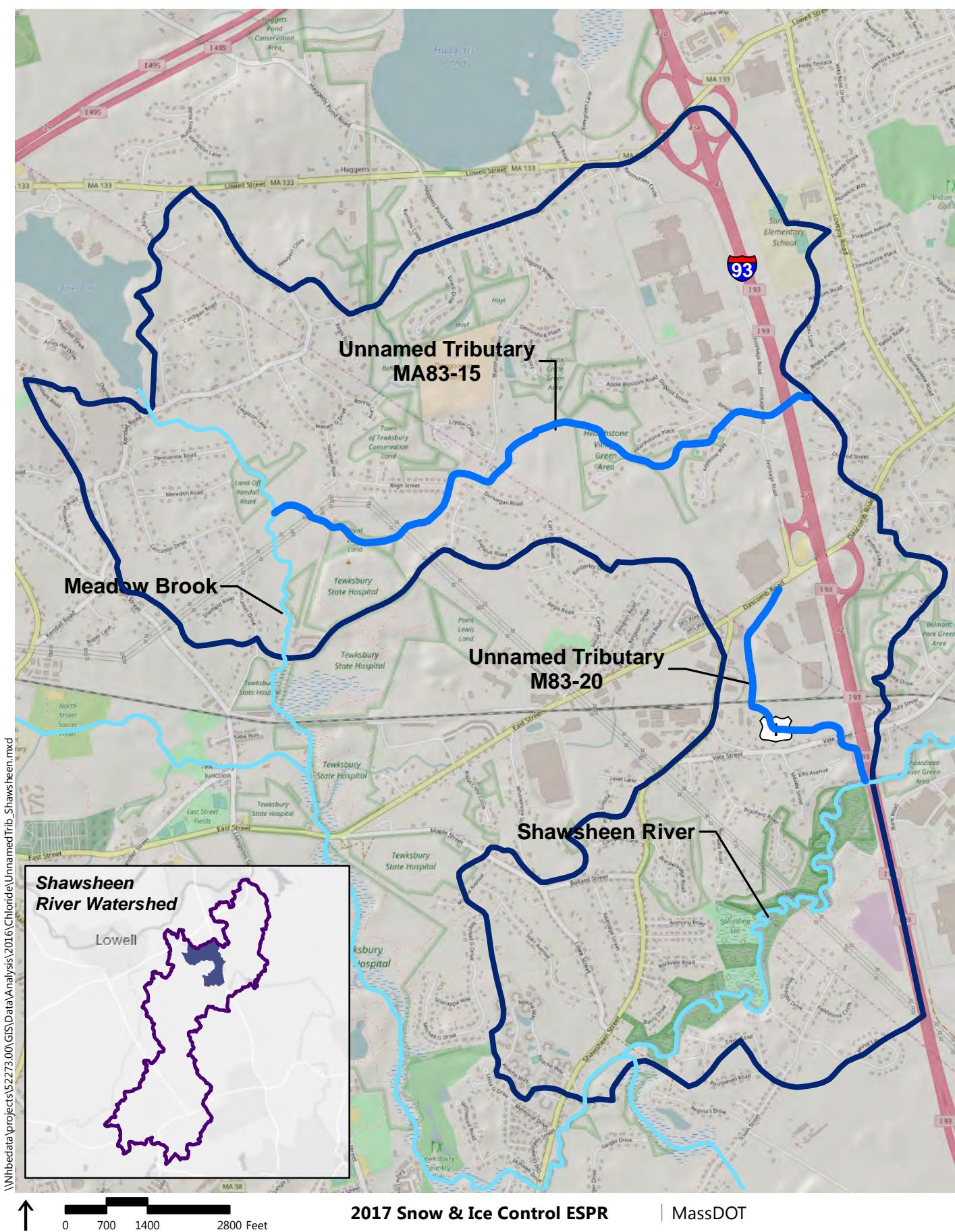
Legend

▲ Salt Shed — River

— Fish Brook - MA84A-40 □ Drainage Sub Basin

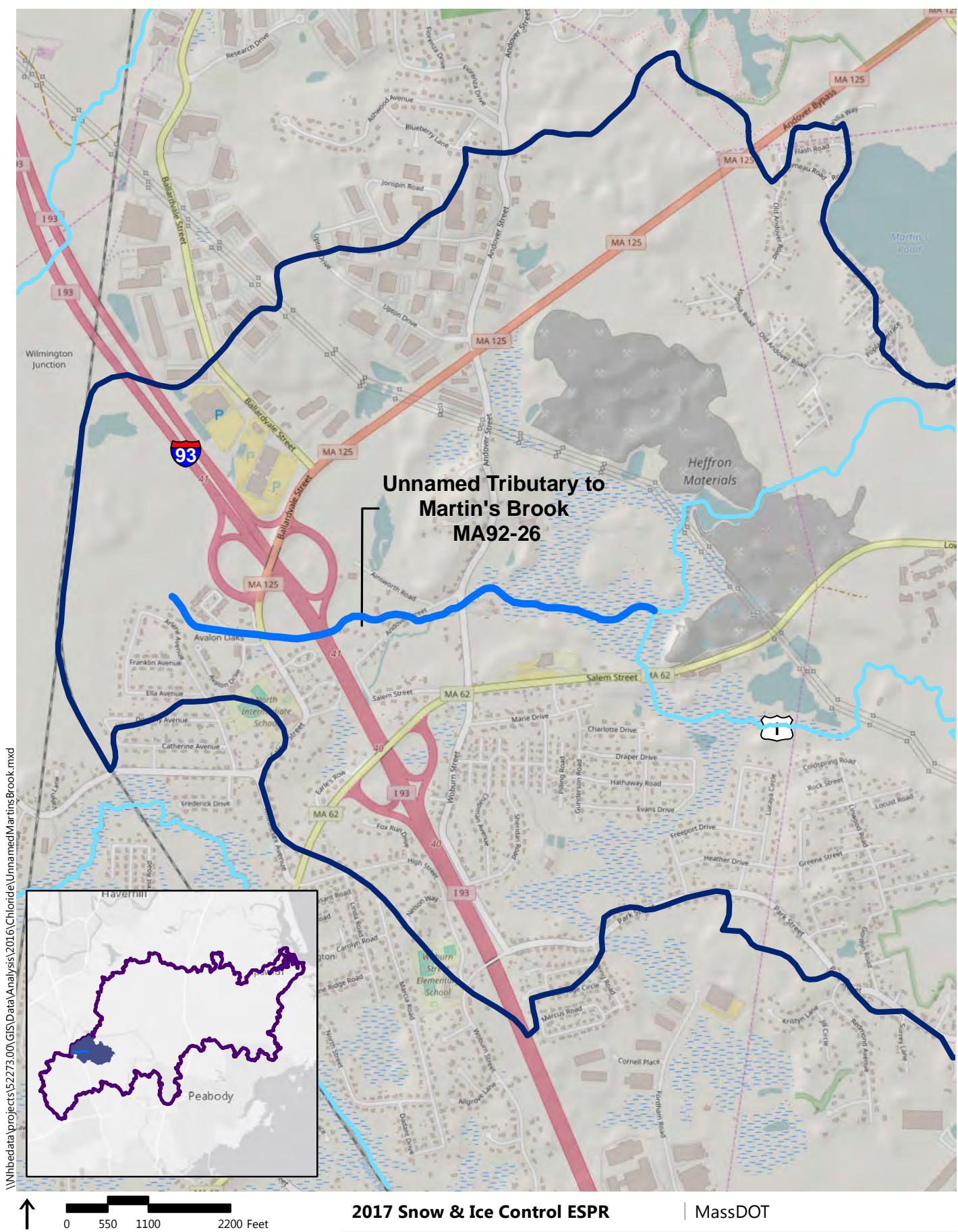
**Chloride Impaired Watershed
Fish Brook - MA84A-4**

Source: MassGIS, MassDOT, VHB



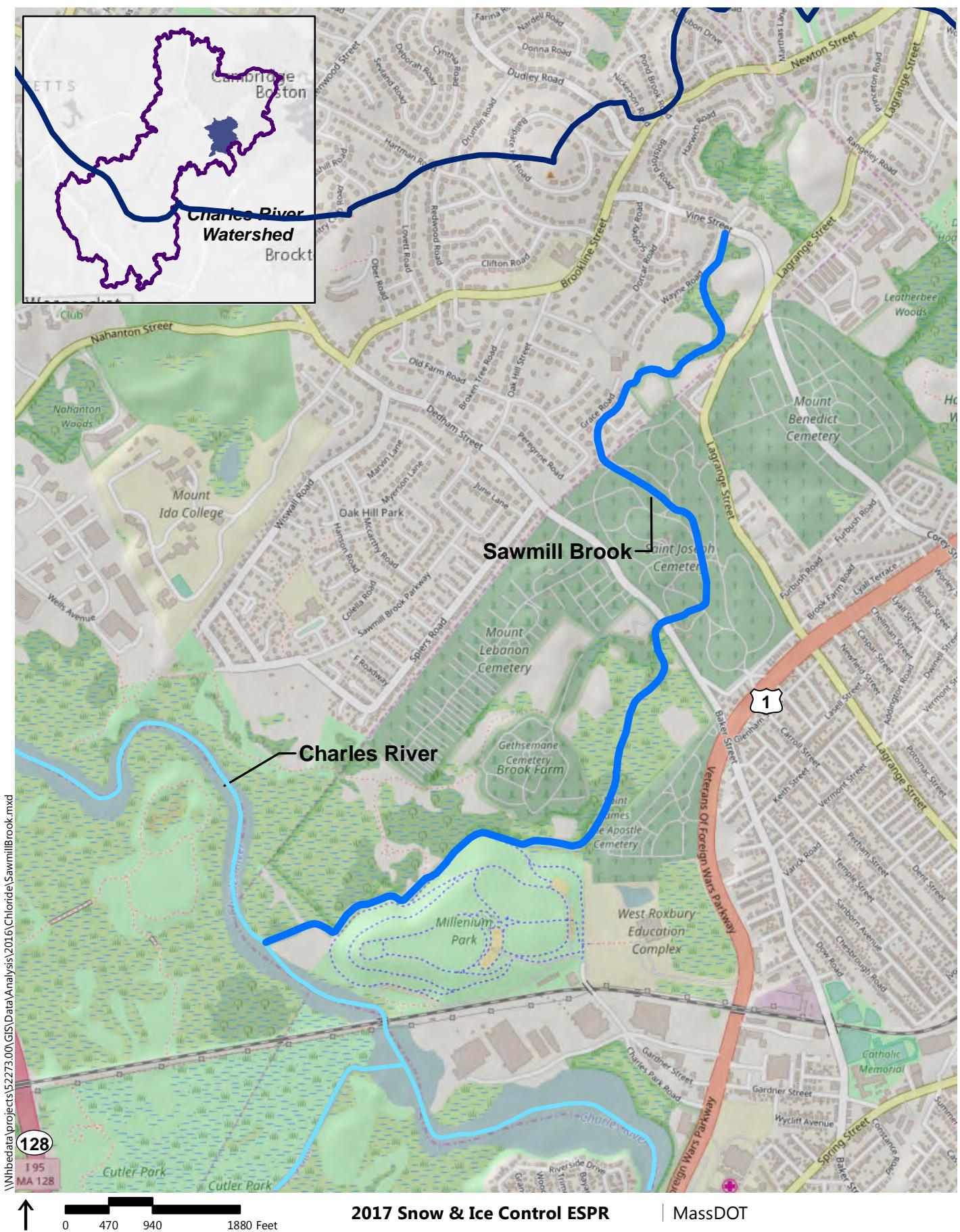
Chloride Impaired Watershed
Unnamed Tributary
MA83-15 and MA83-20

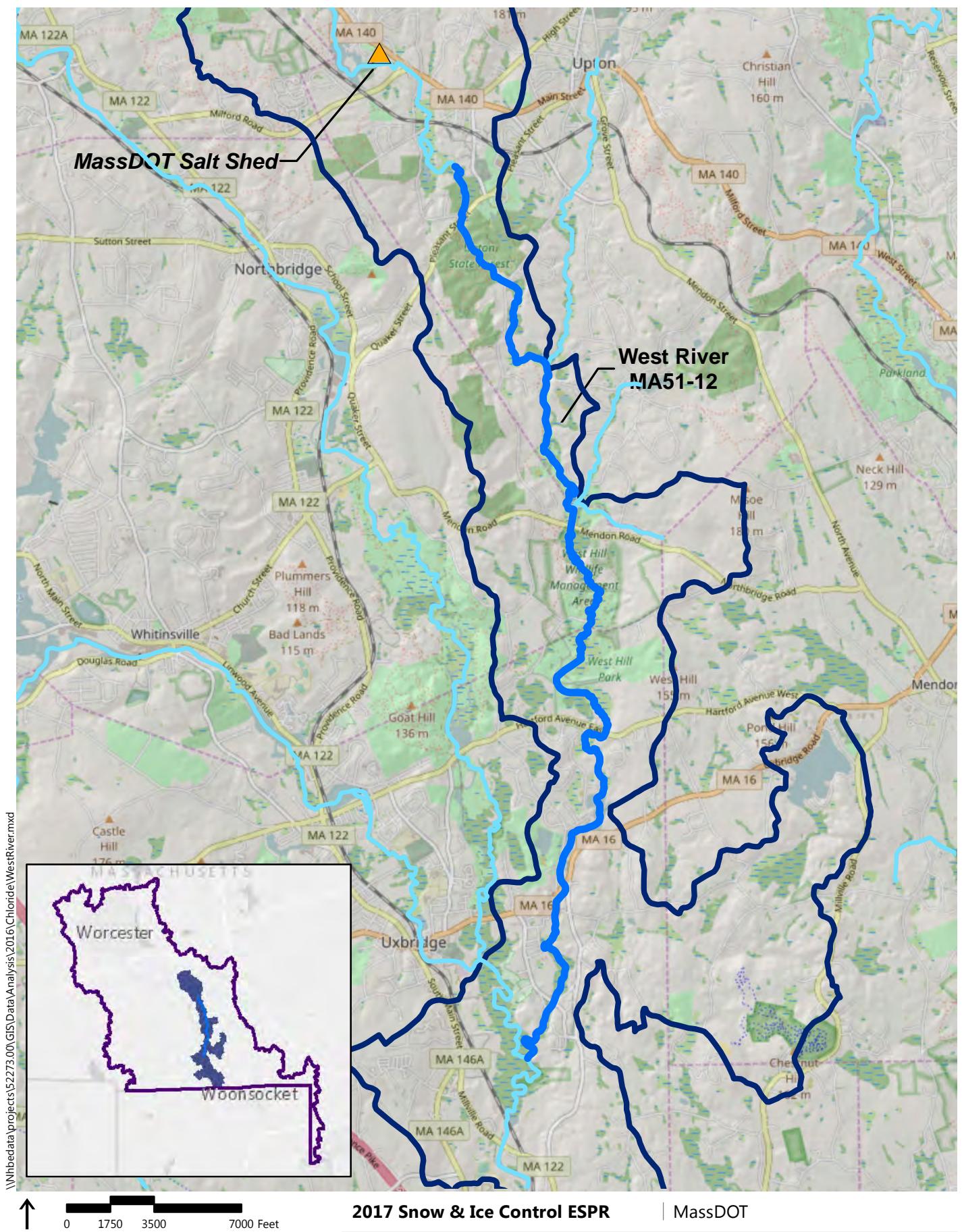
Source: MassGIS, MassDOT, VHB



**Chloride Impaired Watershed
Unnamed Tributary to
Martin's Brook - MA92-26**

Source: MassGIS, MassDOT, VHB





Chloride Impaired Watershed
West River - MA51-12

Source: MassGIS, MassDOT, VHB

Appendix D:

MassDOT Contractor Calibration Form



Attachment I
Closed Loop Ground Speed Control System Calibration
and Data Verification Form

Depot No. _____

Date: _____

Contractor or Company's Name: _____

Vehicle Information

Equipment No. _____ Registration No. _____

Year: _____

Make: _____

Model: _____

Spreader Equipment

Make: _____

Model/Serial No: _____

Closed Loop Ground Speed Control System

Make: _____ Model/Serial No.: _____

Gate Opening 2.5" YES NO Other _____ Volume _____ YD

All vehicles must be capable of consistently dispensing highway-deicing materials at the application rates dictated by the MassDOT's Policy and Procedures relative to Snow and Ice Operations.

MassDOT shall require the transfer of the data gathered by having a closed loop ground speed control system. This information may be transferred by either electronic download, or paper print-out at the contractor's discretion at the end of each event. The closed loop systems will have data logging capabilities and shall include at a minimum, but not limited to the following data: Pounds or Tons of Material Applied, Types of Material, Gallons of Liquid Dispensed, Miles Traveled, Location of Dispensed Material, Lane Miles Applied, Time of Application, Application Rates. The information shall be provided (by the Vendor) to the timekeeper or other MassDOT representative at the Depot. All pre-wetting systems shall be equipped with a flow meter to accurately dispense deicing chemical. All information gathered shall remain the property of MassDOT and used at its discretion.

Authorized Calibration Company: _____

(Authorized Dealer)

Certifies that the above listed closed loop ground speed control system is operating according to the Manufacturers Specifications and that the spreader has been properly calibrated.

Authorized Signature

NOTE: One copy of this completed certification is to be kept in the vehicle and the Original copy shall be submitted to MassDOT's District Office.